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THIS WORK CONSISTS OF SPECIFICATIONS FOR THE PREPARATION OF FINAL DESIGN DOCUMENTS, WITH ONBOARD REVIEW, FOR THE CONSTRUCTION OF FACILITIES TO ELIMINATE THE MIGRATION OF CHEMICAL CONTAMINANTS ACROSS THE NORTH BOUNDARY.

CHAPTERS INCLUDE:

1. GROUND WATER ANALYSIS
2. PERMITS AND REGULATIONS
3. ROADS NEEDED
4. DRAINAGE
5. SPECIFICATIONS FOR THE STRUCTURAL, MECHANICAL, AND ELECTRICAL SYSTEMS.

14. SUBJECT TERMS
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ORIGINAL

DESIGN ANALYSIS

LIQUID WASTE DISPOSAL FACILITY
NORTH BOUNDARY EXPANSION
ROCKY MOUNTAIN ARSENAL
Commerce City, Colorado

FY 80

Project No. 34

Prepared for

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS
Omaha, Nebraska

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May 1980

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CHAPTER I

INTRODUCTION

A. AUTHORITY AND SCOPE.

1. Authority. The Design Documents for the Liquid Waste Disposal Facility, North Boundary Expansion were authorized by Directive No. 14, Design 80-MCA-Omaha District, dated 16 August 1979.

2. Scope. This work consists of the design and preparation of Final Design Documents, with onboard review, for the construction of facilities to eliminate the migration of chemical contaminants through the North Boundary Aquifer Channel.

B. APPLICABLE CRITERIA.

1. General.

Appendix C with Supplement, Instructions for Contract No. DACA45-79-C-0019

2. Publications.

Department of Labor, Occupational Safety and Health Act Standards Manual

Department of the Army Technical Manual, TM 5-809-10, Seismic Design for Buildings

Department of Defense, DOD 4270.1-M, Construction Criteria Manual

Department of the Army Technical Manual, TM 5-822-2, General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas

Department of the Army Technical Manual, TM 5-820-3, Drainage and Erosion-Control Structures for Airfields and Heliports

Department of the Army Technical Manual, TM 5-820-4, Drainage for Areas other than Airfields

Department of the Army Technical Manual, TM 5-810-5, Plumbing

National Electrical Code NFPA No. 70

Life Safety Code NFPA No. 101

National Electrical Safety Code

C. PURPOSE AND FUNCTION. The primary purpose and function of this project is to reduce contaminant levels leaving Rocky Mountain Arsenal to within approved standards. These contaminants are leaking from storage basins, entering the subsurface soil and water table, and in some cases are being transported across the Arsenal boundaries by ground water.

D. GENERAL DESCRIPTION OF WORK.

1. The northern boundary containment and treatment facility (Building 808) will be expanded as follows:

a. Extend the slurry trench containment barrier 3,840 feet to the east and 1,400 feet to the west.

b. Cap the trench with a cover of impermeable clay.

c. Install twenty-nine dewatering wells on the upstream side of the new containment barrier.

d. Install twenty-six recharge wells on the downstream side of the new containment barrier.

e. Install nineteen dewater wells on the upstream side of the existing containment barrier.

f. Connect all new wells to the existing treatment facility.

g. Expand existing Building 808 twenty-five feet to the east.

h. Provide influent and effluent wet wells at Treatment Building 808.

i. Construct a 12-foot wide all-weather perimeter and access road around the new barrier and well system.

j. Provide electrical power service to the entire area.

k. Provide an earth berm crossing at the "D" Street crossing of the containment barrier.

l. Provide a barrier, First Creek crossing, and low water perimeter road creek crossings.

m. Provide a ground water monitoring well system.

n. Provide a 6,000 gallon liquid propane storage tank at Building 808.

* RMA would procure and install a replacement to the Calgon lease carbon treatment system concurrent with the CCE effort

CHAPTER II

ARCHITECTURAL

A. GENERAL.

The existing insulated metal building will be enlarged to provide additional interior space. This will be accomplished by adding a 25 by 40 foot extension to the east end of the existing 40 foot wide building. The added area will be the same height as the existing building.

All new components used in the addition, except insulation, will match existing components in material type, gage, profile, color, etc. and will provide proper fit with existing components when installed.

Insulation for the metal building addition will be mineral fiber semi-rigid board with a vinyl vapor barrier face sheet. This material will replace the existing painted foam board because of the fire hazard of exposed foam materials. These materials, including urethane, extruded polystyrene, and expanded polystyrene will not be used because of their ability to ignite easily and to produce toxic smoke.

A sliding sash window, a personnel door, and an overhead-type door will be removed from the existing end wall and reinstalled at the same relative locations in the new end wall. The openings from which the doors are removed will be retained for passage between the new and existing building areas. The opening from which the window is removed will be closed.

Existing building components reused in the new construction will be touchup field painted as required to provide a like new finish. If existing components are damaged beyond reasonable repair during the construction process or otherwise unusable, they will be replaced with matching new components.

CHAPTER III

STRUCTURAL

A. SCOPE OF WORK. A listing of references applicable to this section is found in the introduction to this Design Analysis. Recommended structures to be provided by this project include the following:

1. Foundation slab and footing for expansion of existing treatment plant building.

2. Reinforced concrete influent and effluent wet well.

The design information listed in this section is applicable to all structures.

B. FOUNDATION DESIGN DATA.

1. Depth. A minimum depth of 3.5 feet below final grade was used for all foundations to protect against frost damage.

2. Bearing pressures. Footings were sized for a maximum allowable soil bearing pressure of 1,400 pounds per square foot.

3. Earth pressures. For design of walls below final grade, a fully saturated earth pressure was used.

C. DESIGN LOADS.

1. Roof live load, 30 psf.

2. Floor live load

    a. Slab on grade, 150 psf

    b. Suspended slab, 100 psf

3. Wind load.

    a. American National Standards A58.1-72 and as amended

b. High loss potential facility

c. 100 year mean recurrence interval

d. Exposure "C"

e. Basic wind speed = 85 mph

4. Seismic, Zone 1, Z = 0.25 designed in accordance with TM 5-809-10.

D. FLOOR SLABS.

1. Slab on grade over 6-inch layer of capillary water barrier.

2. Structural floor, concrete slab.

E. MATERIALS.

1. Concrete.

a. Class AA, 4000 psi compressive strength at 28 days for concrete wet wells.

b. Class A, 3000 psi compressive strength at 28 days for all concrete not otherwise noted.

c. Reinforcement, ASTM A 615 or ASTM A 617. Ties and stirrups, Grade 40; all others Grade 60.

F. VIBRATION. The only mechanical equipment which will be installed on the structures are pumps and motors. Vibrations produced by this equipment will be readily absorbed by the concrete structure without any adverse effects. Isolation of the equipment from the structure is not required.

G. ALTERNATIVES. There are no structural systems competitive with reinforced concrete for the facilities included in this project.

CHAPTER IV

MECHANICAL

A. CRITERIA LISTING.

1. Publications.

Department of Defense Manual, DOD 4270.1-M, Construction Criteria Manual

Department of the Army, TM 5-810-1, Mechanical Design-Heating, Ventilating, and Air Conditioning

Department of the Army, TM 5-810-5, Plumbing

Department of the Army, TM 5-810-6, Mechanical Design - Gas Fitting

Department of the Army, TM 5-785, Engineering Weather Data

Project Development Brochure, Rocky Mountain Arsenal, Liquid Waste Disposal Facility, North Boundary expansion, Revised 31 July 1979

U.S. Army Engineer Waterways Experiment Station, Engineering and Construction Materials Compatibility Study

Minutes of review meetings of February 14 and 15, 1980, February 28 and 29, 1980, and April 29, 1980

B. DEWATERING AND RECHARGE SYSTEM.

1. Design Conditions.

a. Contaminated ground water flows northward to be intercepted by an impervious barrier. A total of 35 dewatering wells will remove contaminated ground water from the alluvial aquifer. Nineteen dewatering

wells will remove contaminated water from the Denver Sands for treatment and reintroduction through 38 recharge wells. These recharge wells are located on the north side of the barrier. The dewater wells will be divided into three treatment areas corresponding to the areas in which three different combinations of contaminants are found. Dewatering flow rates range from 3.5 gpm to 23 gpm. Recharge rates range from 6 gpm to 29 gpm.

b. Six dewatering wells and twelve recharge wells presently exist and will be incorporated into the new system. The existing dewatering wells contain submersible pumps of 20 gpm capacity at 90 feet of head. Pump motors are 460 volt, 3-phase, 3/4 horsepower each. All existing wells will be modified to meet the design of the new wells.

2. <u>System Description</u>.

a. Dewater system.

(1) Each dewater wellhead will extend aboveground through a concrete slab. The concrete slab will be located atop an earth mound sized to place the wellhead above the flood plain.

(2) Dewater well pumps will be submersible, centrifugal type of materials shown to be suitable according to the U.S. Army Engineer Waterways Experiment Station, Engineering and Construction Materials Compatability Study. Motors will be 240 volt, single-phase. Pumps will be controlled by level sensing electrodes suspended in the well. The sensors will be set to turn the pumps on and off at water levels determined from the geotechnical analysis. The pump will be suspended in the well by a 1-1/4-inch diameter corrosion resistant steel pipe.

(3) Each pump will be equipped with a turbine type flow meter of corrosion resistant steel with a local readout of gpm flow, as well as a totalizer. Appropriate balancing valves and check valves made of polyvinyl chloride (PVC) will be placed in line with the meter and connected by 1-1/2 inch Schedule 80 PVC pipe. The meter and valves will be located above the concrete slab and, after the last valve, the PVC pipe will turn down through the slab to a distance of 5 feet below ground level (below maximum frost penetration). The valves, meter, and piping above the concrete slab will be protected from freezing by a thermostatically controlled, self limiting, pipe trace heating system. The valves, meter, pipe, and tracing will be covered by insulation tape.

(4) The concrete slab will be covered by a metal bulkhead door set on a concrete curb around the perimeter of the slab.

(5) The dewatering wells will be connected to the treatment influent wet wells by means of an underground collection header of Schedule 80 PVC plastic pipe. The three treatment sections will be isolated by gate valves placed in the header in such a way that the boundary of any section may be extended by addition of wells from an adjacent section. Valves will be accessible to the surface by cast-iron valve boxes to allow valve operation by key. The PVC manifold pipe connecting a given treatment section header with the wet wells will lie in the same trench as the section dewater header. At the point where all three manifold lines meet, they will be run in the same trench to the wet wells.

(6) Well placement is determined from geotechnical analysis using data derived from pump tests and computerized modeling of the alluvial

aquifer system. Pipe sizes are selected by balancing minimum friction loss against minimum pipe diameter (minimum cost).

(7) The total head loss in the system is determined by use of the Water Distribution Analysis computer program. Input to the program includes pipe length, diameter, and roughness, input flow rates, and desired outflow pressure. Output from the program includes head loss and function pressures. The output from the program is included in the mechanical calculations. The head loss output from the computer program is used to select pump horsepower from manufacturers' catalogs.

(8) Construction materials for pumps, pipe, valves, etc. used in the dewatering system are based on results of the Engineering and Construction Materials Compatibility Study by the U.S. Army Engineer Waterways Experiement Station. Using agency experience confirms that PVC is the most suitable material. Stainless steel will be used for those items not in PVC.

b. Recharge System.

(1) Each recharge wellhead will extend aboveground through a concrete slab. The concrete slab will be located atop an earth mound sized to place the wellhead above the flood plain.

(2) The concrete slab will be covered by a metal bulkhead set on a concrete curb around the primeter of the slab.

(3) Recharge pumps will be vertical turbine pumps of conventional construction located in the organic treatment plant effluent wet well. Duplex pumps, controlled through an automatic alternator by electrode type level sensors, will be used.

(4) Each recharge well will be equipped with a turbine type flowmeter identical to those installed on the dewater wells. A pressure regulating valve will be provided to ensure even distribution of flows between the wells. Appropriate balancing valves will also be provided at each well.

(5) The recharge wells will be connected to the recharge pumps with an underground pipe of unrestricted materials.

(6) Each recharge well will also have a solenoid operated shutoff valve actuated by a high level electrode probe which will close the well should the ground surrounding the well become incapable of accepting recharge water. In the event that all 38 recharge wells are closed at the same time, a pressure relief valve in the overflow pit will open, allowing the recharge water to discharge into the ditch leading to First Creek. The only foreseeable condition whereby all wells would close and the overflow valve would open would be a major flood by First Creek. Under these conditions, the relatively small amount of water padded to First Creek would be inconsequential. It will not be necessary to shut down the dewatering wells and treatment plant when the overflow valve opens. The overflow valve pit will also include a cumulative water meter in order to account for any water discharged directly into First Creek.

C. BUILDING 808 EXPANSION.

1. <u>Design Conditions</u>.

a. Building 808 will be expanded to house interconnecting piping and the motor control center. Ventilation will be provided by gravity ridge vent and heating will be provided by an LP gas-fired unit heater.

b. Design Temperature.

	Inside	Outside
Summer	101 degrees FDB	91 degrees FDB
Winter	65 degrees FDB	-5 degrees FDB

2. System Description.

a. Treatment system influent pumps will be vertical turbine pumps, constructed entirely of corrosion-resistant materials. One pump will be provided for each dewatering stream and will be located in the treatment plant influent wet well immediately outside Building 808. Pumps were selected for capacity of 250 gpm and discharge pressure of approximately 60 psig. The discharge pressure was selected by using agency personnel based on the pressure requirements for the new organic treatment process.

b. Summer ventilation of the building expansion will be provided by a 9 foot-0 inch section of gravity ridge ventilator with a 9-inch throat. A manually-operated damper allows the vent to be closed in winter. The vent, operating a 10 degree temperature difference, will provide 1,800 cfm of outside air, which is more than sufficient to maintain a 10 degree temperature rise inside.

c. Heating will be provided by a ceiling hung LP gas-fired unit heater of 71,467 Btuh capacity. Unit will be controlled by a wall thermostat.

d. Interconnecting piping will be provided for connection to the organic treatment process under another contract. The piping material will be Schedule 80 PVC in accordance with Engineering and Construction Materials Compatibility Study. Appropriate valves will be installed to allow for a completely flexible operation.

CHAPTER V

ELECTRICAL

A. GENERAL. This design is based on, but not limited to, the applicable publications, codes, and specification listed in the introduction to this narrative.

B. SCOPE. This design will generally consist of the following details:

1. Interior.
    a. Lighting and receptacles
    b. Service entrance
    c. Motor control center
    d. Dewater well control
    e. Recharge well service
2. Exterior.
    a. Primary service
    b. Transformers
    c. Overhead distribution
    d. Well control cable

C. INTERIOR.

1. Lighting, 175-watt mercury vapor fixtures, will be provided and will match all existing fixtures. Switches shall be installed at the doors. Voltage will be 120 volts.

2. Receptacles will be provided in two locations and will be 20 amperes, 120 volt, duplex type.

3. Conduit system will be rigid aluminum or zinc-coated steel.

4. Conductors will be copper with insulation conforming to the NEC. Conductors will be installed in dry locations, damp locations, underground and submersible locations. Conductors for the well controls will be underground telephone type.

5. Service entrance to the building will be relocated in the new building extension. The service will be underground into the new motor control center. The existing MCC will be served from the new MCC-1. Service will be 480 volt, 3-phase. Service entrance to each dewater well will be underground 240/120 volt, single-phase. A breaker will be provided at each well.

6. Motor control center will be located in the new building extension. The MCC will serve the existing MCC, five new pumps, and the recharge wells. Future provisions will be made for adding one additional section to serve five pumps and additional loads. The MCC will contain starters for the new pumps. A load of 50 kVA was used for the existing MCC according to instructions received from Rocky Mountain Arsenal.

7. Existing panels, 240/120 volt, will be used to serve the new 120 volt loads.

8. Motors at the building will be vertical type, totally enclosed, located outside at the wet wells. Motors at the wells will be submersible.

9. Well control panel will be located in the building for remote control of the dewater wells. The panel will have an OFF-ON switch and a red light for each well. The panel will turn off the wells when a high water level is reached in the appropriate wet well. The panel will have a local bell and light for visual and audio notification. A remote alarm

system will transmit a signal over telephone lines (provided by others) to the fire station. The fire station will have an alarm box which will sound the local alarm.

10. Dewater well control will be at each well. The pump will be controlled by a local Hand-Off-Automatic (H-O-A) switch. In the AUTO position, a level probe contact and the remote OFF-ON switch contact will cycle the pump. The remote OFF-ON switch and red light will be operated by induction type well control relays which use telephone type wire. One pair of telephone wires will be routed underground from each well to the well control panel in the building. A heat tape will be provided in each well for freeze protection.

11. Recharge well will be provided with 480 volt, single-phase underground service. A 480/120 volt transformer will serve a level controlled solenoid and heat tape at each well. A breaker will serve as a disconnect and protection device.

12. Existing dewater wells will be revised to raise the wellhead above grade. Electrical service will be changed from 480 volt, 3-phase to 240 volt, single-phase in order to standardize all pumps. All electrical equipment will be removed and reinstalled as needed.

D. EXTERIOR

1. Primary service to the existing building is 13.2 kV, 3-phase, 4-wire. The transformers are three 25 kVA, single-phase, 13.2 kV-480 volt. The utility company is presently providing secondary power service at 480/277 volt. The utility company will remove their equipment and provide primary power with metering at 13.2 kV. The new service to the wells will

be 13.2 kV, single-phase, line-to-line. Construction will be suitable for future expansion to 3-phase. A new service will be provided for the new building at 13.2 kV, 3-phase to the new transformers.

2. Transformers will be provided to serve the new building. Three 50 kVA pole-mounted single-phase transformers will provide 13.2 kV-480/277 volt, Delta-Wye service. Transformers for the service to the well will be single-phase, 13.2 kV-240/120 volt pole-mounted. Sizes vary from 15 to 37-1/2 kVA. All service to the building and wells will be underground.

3. Aerial conductors for the primary line will be based on ASCR, size No. 2. Secondary conductors will be No. 2 aluminum, triplex and No. 2 copper underground.

4. Fused cutouts and lighting arrestors will be provided at each transformer.

5. Telephone type cable will be routed underground to each of the dewater wells for control. The cable will be routed in the trench with dewater piping.

6. Existing 480 volt overhead lines will be removed and salvaged.

7. Existing light poles at the building will be relocated because of a new wet well.

CHAPTER VI

GROUND WATER CONTAINMENT ANALYSIS

A. INTRODUCTION.

1. Background.

a. The Rocky Mountain Arsenal has received a Cease and Desist Order from the State of Colorado to prevent further migration of contaminated water across its North Boundary. Contaminants related to liquid wastes resulting from the past manufacture of chemical warfare agents and recent manufacture of herbicides, pesticides, and fungicides have reached the saturated zone and are being transported by ground water. Ground water flow is generally to the north and northwest toward the South Fork Platte River.

b. Ground water is generally transmitted by porous media under both unconfined and confined conditions with intermediate degrees of confinement. Aquifers consist of shallow unconsolidated sands and gravels overlying relatively dense sands of the Denver Formation that are interbedded with shales and siltstones. The Denver Sands consist of irregular lenticular shaped beds confined by more extensive siltstones and shales. The shallow unconsolidated aquifer consists of channelized alluvial deposits that are absent or unsaturated in some areas. Ground water is generally unconfined in the alluvial aquifer, but locally clayey or silty saturated soils result in semiconfined conditions. The alluvium is generally much more permeable than the underlying Denver Sands.

c. The contaminants that are to be intercepted and treated are DIMP, DBCP, DCPD and Fluoride ions. Relatively high concentrations of these control constituents are transported by ground water flow in the shallow alluvial aquifer. DIMP, DCPD and Fluorides are concentrated in plumes primarily in the western part of the alluvial aquifer. DBCP is more widely spread resulting in a decision to contain and treat all of the alluvial aquifer flow across the North Boundary. Low level concentrations of these control constituents have also been detected in the underlying Denver Formation. The need for containment in this formation is somewhat inconclusive because the latest and more reliable monitoring data indicates that this water probably meets drinking water standards. However, selective containment combined with close monitoring of possible contaminated zones within the Denver Formation is planned.

d. Studies of this problem by various U.S. Government agencies and consultants have been carried out dating back to the 1950's. Detailed studies of containment systems for the North Boundary have been in progress since the mid 1970's. A pilot containment and treatment facility was constructed in 1978. This facility has successfully developed operational data and intercepted a large percentage of contaminant migration across the North Boundary in the alluvial aquifer. It was decided to extend this facility to contain contaminant flow.

2. Containment Design Concept.

a. A pilot containment facility consisting of a slurry trench cutoff wall, dewatering wells, treatment plant, and recharge wells has been in successful operation since the summer of 1978. This facility will be

expanded by extending the cutoff wall 3,840 feet east and 1,400 feet to the west. Additional dewatering wells will be provided to intercept all of the flow in the alluvial aquifer and suspected or possible contaminated flows in the upper Denver Sands. Treatment capacity will be expanded and additional recharge wells provided to reinject treated water to essentially restore the natural flow system.

b. The concept adapted by RMA and COE, based on criteria received from RMA, requires detailed quantification of flow and contaminant fluxes for each segment of the alluvial aquifer, so that three zones of flow can be intercepted and manifolded to separate treatment modules. Dewatering wells have to be distributed across the entire flow system to minimize dispersion of contaminants by gradient changes. This concept required development of a digital finite-difference flow model to define the distribution of flow through the system with the degree of accuracy required to make this concept technically feasible.

c. Alluvial aquifer dewatering wells upgradient from the cutoff wall are to selectively intercept three zones of contamination by mainfolding groups of wells across the barrier, thus permitting separate treatment of these waters. The dewatering rate will be as close to the natural flow rate as possible. The dewatering rate will have to slightly exceed the natural flow rate, at least during initial years of operation, to prevent excessive rise in water levels and flooding over the cutoff wall in low lying areas.

d. The cutoff wall extensions will be constructed by excavating bentonite slurry trenches which will be backfilled with select material

mixed with bentonite clay to form a hydraulic barrier through the alluvium and into the Denver Formation. The cutoff wall extensions will penetrate shallow Denver Sands that have or are close to having hydraulic connection with the alluvial aquifer at the barrier. Additionally, the cutoff wall will penetrate fractured shales to provide protection against fracture flow through the underlying shales.

e. The existing slurry cutoff wall will be left undisturbed because analyses indicate that the existing barrier is quite adequate. There is a shallow and rather extensive Denver Sand layer beneath the existing barrier that contains low levels of contaminants. Flow through this sand layer will be intercepted by Denver Sand dewatering wells, although the flow through this sand layer is only about 0.75 gpm under existing gradients and available analyses indicate this water meets standards for DIMP, DCPD, DBCP and Fluorides. Concern has been expressed about flow through fractures in shales between the base of the existing barrier and the underlying Denver Sand. Computations indicate this flow, if not intercepted by the Denver Sands dewatering wells, would amount to only 0.06 gpm. Even if Denver Sand dewatering wells are not constructed, flow beneath the existing cutoff wall would be and is insignificant, totaling only 0.81 gpm under natural gradients. Therefore, it is ESA's recommendation that the existing pilot cutoff wall be left undisturbed (it should not be deepened) and that Denver Sand dewatering wells be used to monitor the quality of flow and dewater the shallow Denver Sand on an as needed basis. Also, it is recommended that monitoring wells be constructed in the clay shales immediately beneath the existing cutoff wall to determine if fractures transmit contaminated flow.

f. Denver Sands dewatering wells will be constructed to intercept suspected or possible contaminated flows beneath the cutoff wall in the Denver Sands to depths of up to 105 feet. A pumping depression will be developed to contain and collect these flows. Contaminant levels are expected to generally meet water quality standards for the control constituents, and the wells will be monitored closely and pumped on an as needed basis.

g. Recharge wells constructed downgradient from the cutoff wall will reinject the treated water. Recharge will be distributed across the flow system so that natural flows are maintained within the constraints of barrier operation. It is estimated that about 110 percent of the natural alluvial flow will be recharged because of the overpumping requirement for operation of dewatering wells, at least during the initial years of operation. Pumpage from the Denver Sands will also be recharged into the alluvial aquifer. This amount is expected to be insignificant in comparison with alluvial flows.

3. Methodology.

a. Existing data including reports and field logs were collected and analyzed. Data stored on magnetic tapes were screened and coded for retrieval in a usable form. Field data including logs and pump test data were used to check computer outputs and data interpretations. Preliminary geologic sections were constructed, water levels and chemical data were contoured, and time concentration graphs were constructed. Existing pump test data were reinterpreted for hydraulic parameters.

b. A field exploration program was planned and performed to provide more detailed geologic, geohydrologic, and chemical data. Along the cutoff wall alinement, 30 test holes were drilled of which five were converted to monitoring wells by installing casings and screens. The alluvium was sampled with a split-spoon and the Denver Formation was cored. Laboratory tests were run on soil samples for gradation and on limited cores for unconfined compressive strength. Four test wells, each with two or three observations wells, were constructed in the alluvial aquifer (2) and the Denver Sands (2). Pump tests were performed and the data were interpreted to determine aquifer characteristics.

c. A finite-difference model was developed of the North Boundary area alluvial flow system to simulate flow conditions and to support the design of dewatering and recharge wells. The design concept of selective interception of contaminant flows required a rigorous analysis of flows across the boundary that could best be simulated and analyzed with finite-difference techniques. This model enabled simulation of flow segments across the boundary within the limits of precision of the hydraulic conductivity data and the water level contours used for calibration of the model. The model was then used to distribute dewatering and recharge rates for wells and simulate the hydraulic effects on the alluvial flow system.

d. Contaminant fluxes for each control constituent were estimated for each dewatering well based on hydraulic effects simulated by the model and evaluation of contaminant plumes. Also, upper limit fluxes were estimated for each dewatering well based on the highest concentrations upgradient from the barrier system. Dispersion and sorptive effects were

ignored in these estimates, resulting in conservative values, especially for upper limit estimates.

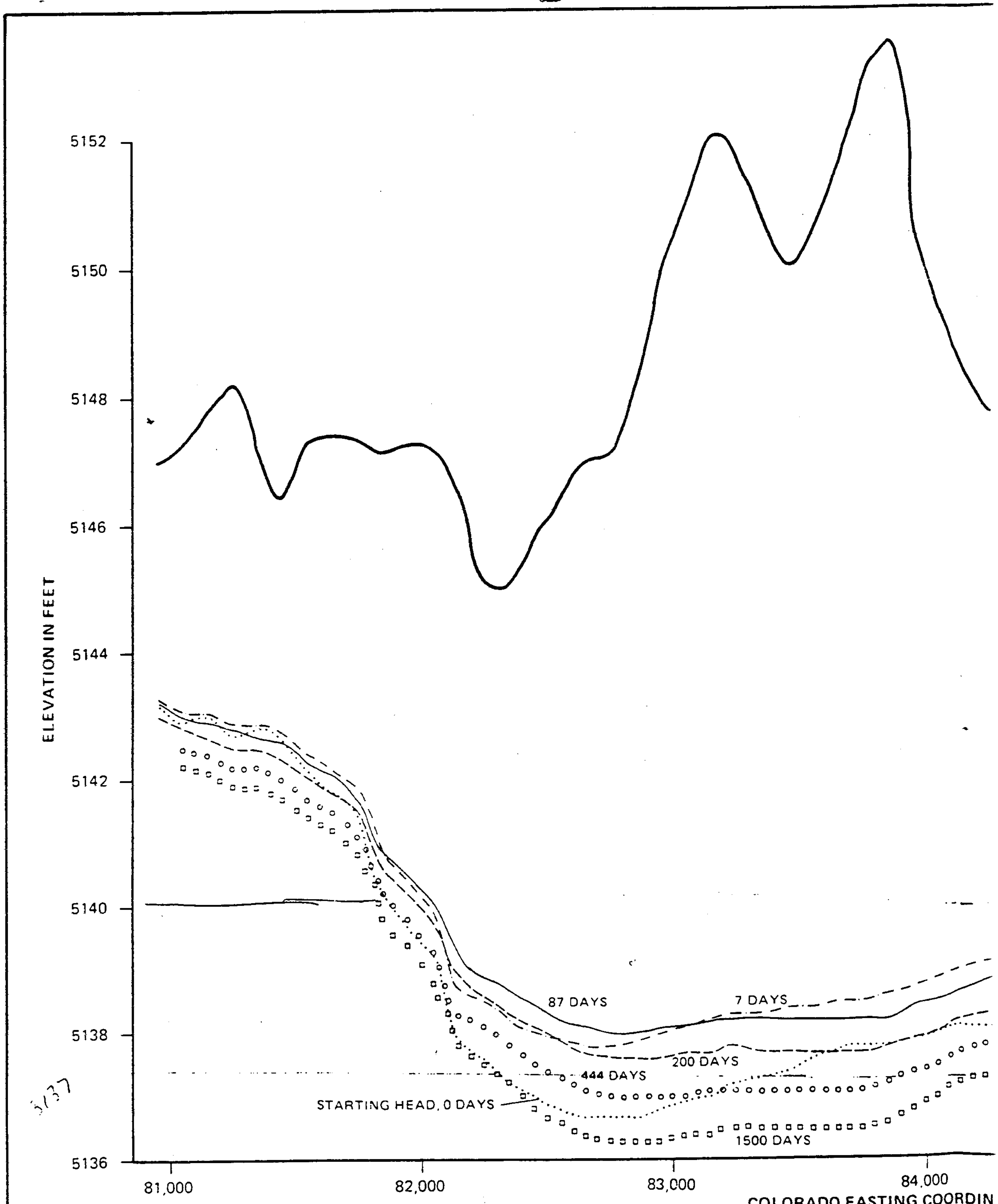
e. Pump tests of two test wells in Denver Sands were used to design dewatering wells. These wells are designed to develop a pumping trough to intercept possible contaminated sands. Distance drawdown calculations were used to design well spacing and pumping rates. Because of the irregular configuration and location of sand lenses, these calculations are only approximate and adjustments in pumping rates may be required. Also, it is possible that additional wells may be required where wells penetrate thinner or less permeable sand (if contaminant levels are found to be high enough to require containment).

f. The slurry cutoff wall extensions were designed as geologic and soils data became available, independent of geohydrologic and chemical studies. Specifications were prepared based on existing data, and backfill requirements were evaluated after gradation tests of soils were completed. Excavation requirements were incorporated into design drawings as they became available.

g. Specifications and design drawings were prepared for alluvial aquifer dewatering and recharge wells, Denver Sands dewatering and for monitoring wells.

h. Monitoring wells for the alluvial aquifer and the Denver Sands were located. Existing wells were incorporated as much as possible into the monitoring system. In many cases only general designs can be provided because of lack of subsurface information.

(1)



SIMULATED GROUNDWATER PROFILES, 5
AFTER INITIATION OF PUMPING

(2)

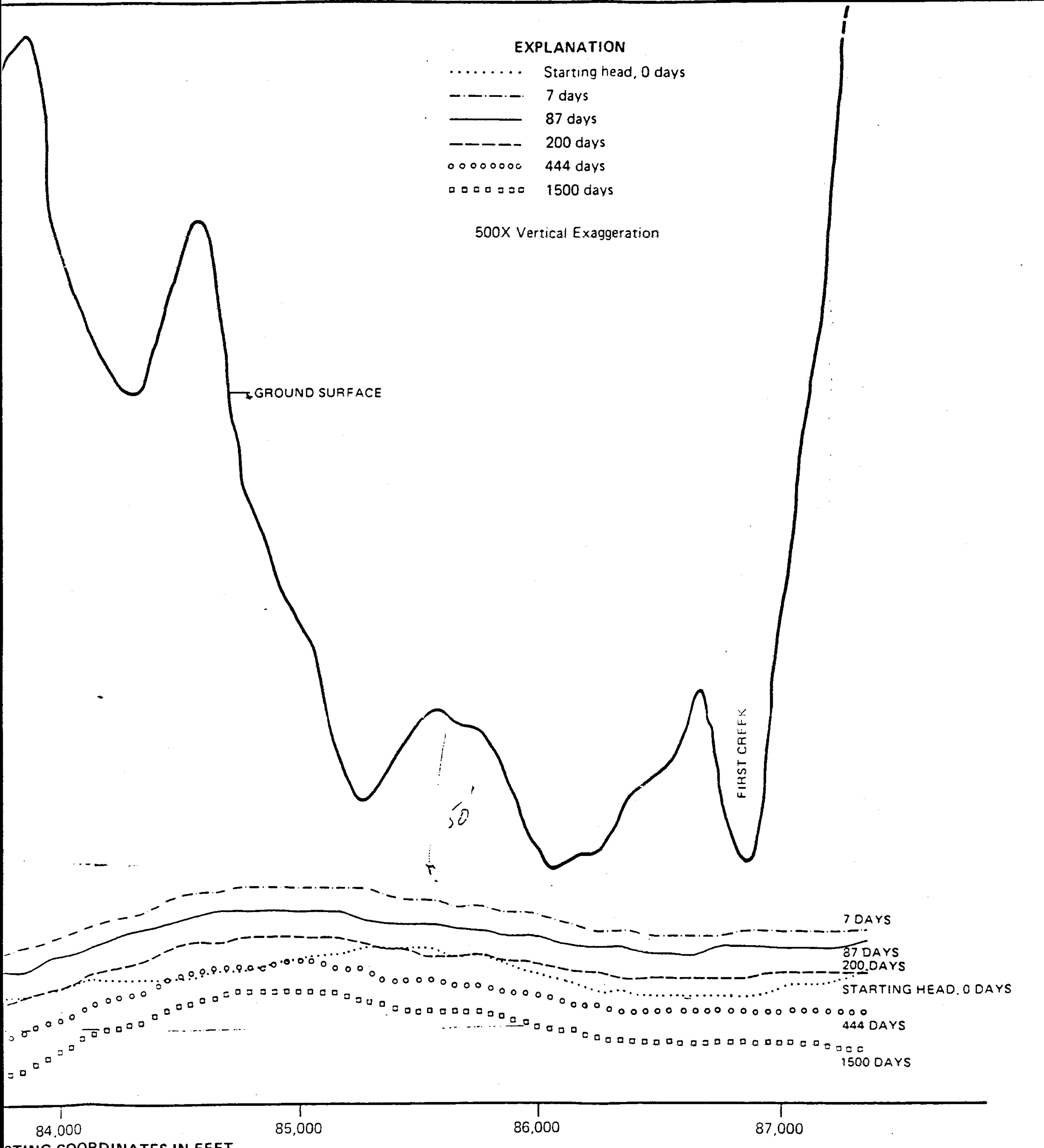


Figure VI-8

R PROFILES, 50 FEET SOUTH OF BARRIER,
N OF PUMPING AT DESIGN RATES

4. Exploration Program.

a. Field work for the project commenced January 3, 1980 and was completed March 23, 1980. A total of 48 holes were drilled (Numbers 1000 through 1047) to depths ranging from 20.5 feet to 80.0 feet. Thirty holes were located along or adjacent to the proposed barrier alinement; 18 holes were located in the vicinity of the recharge and discharge well alinement. A total of 19 of the holes were completed as wells. Sieve analyses were run on 62 samples within the alluvium. Between one and four drill rigs were operating on the site, five to seven days per week. Drilling companies used for the project were Custom Auger Drilling and Virginia Drilling, both of Denver, Colorado.

b. Terminology used on field logs and qualitative as well as quantitative sample assessment methods are described in ESA's Field Exploration Manual. Certain classifications used by ESA field personnel may differ slightly from the U.S. Army Corps of Engineers usage.

c. The 30 exploration holes drilled along or adjacent to the proposed barrier alinement included Numbers 1000 through 1029. East of the existing pilot barrier, depths ranged from 65.5 feet to 75.2 feet and 49.9 feet to 80.8 feet along and to the west of the existing pilot barrier. These holes were drilled utilizing the following procedure: A 6-inch flight auger was used to auger through the alluvium and standard split-spoon samples were driven approximately every 5 feet. Five and one-half

inch, temporary steel casing was then placed within the alluvium and partially into the weathered Denver Formation. The Denver Formation was cored continuously with PQ-3 wireline coring equipment. Diamond bits and three different types of carbide bits were used. The holes were geophysically logged by Colorado Well Logging of Golden, Colorado. Spontaneous potential, resitivity, gamma, gamma-gamma, neutron, and caliper logs were run on each hole. Twenty-five holes were backfilled with a 50-50 slurry mixture of bentonite and cement. Five holes (Nos. 1024, 1021, 1019, 1018, and 1017) were completed with isolated well screens utilizing a bentonite seal at the bottom, a filter pack of pea gravel around the screened interval, a bentonite seal above the screened interval, and a 50-50 slurry mixture of bentonite and cement to the surface. The temporary steel casing was removed from all of the holes.

The 18 holes located in the vicinity of the recharge/discharge well alinement (Nos. 1030 through 1047) were drilled using a 6-inch flight or hollow stem auger, or 5-inch, 8-inch, or 11-3/4-inch tricone bits. Depths of the holes ranged from 20.5 feet to 67.0 feet. Standard split-spoon samples were driven approximately every 5 feet in Holes 1030, 1031, 1033, 1034, 1035, 1037, 1038, 1039, and 1040. Four holes, 1032, 1036 (alluvium), 1041, and 1045 (Denver Sand), were completed as wells. Steel casing and screen 6 inches in diameter was installed in Wells 1031 and 1036, and a gravel envelope was used around the screen. Wells 1041 and 1045 in the Denver Sand were completed using 4-inch slotted PVC and a thin gravel envelope. A conductor casing was cemented into the alluvium above the screened zone. Pump tests were run on these holes for up to five days.

Nine holes, 1030, 1031, 1033, 1034, 1042, 1043, 1044, 1046, and 1047, were completed as observation wells using 2-inch slotted PVC pipe. The five holes not completed as wells, 1035, 1037, 1038, 1039, and 1040, were back-filled with a 50-50 slurry mix of bentonite and cement.

B. HYDROGEOLOGY.

1. General.

a. The Rocky Mountain Arsenal is located in the Denver Basin near its northwestern flank. This basin is a broad asymmetrical synclinal trough filled with marine and continental sedimentary deposits ranging in age from Permian to Quaternary. The axis of the syncline is closer to the western margin of the basin and trends through the southeastern corner of the arsenal area. There is an erosional break (unconformity) between Pleistocene and Recent superficial deposits and older Paleocene-Upper Cretaceous rocks with most of the Tertiary section absent. This erosional break forms an abrupt separation between the relatively low density, essentially unconsolidated surficial deposits and older, relatively dense sedimentary rocks. The Paleocene and older rocks are often termed bedrock in this area although they often exhibit dense soil characteristics. When the term bedrock is referred to in this report and in design drawings, it refers to materials that are often marginal or transitional between dense soils and rocks in the engineering or practical sense.

b. At the Rocky Mountain Arsenal the bedrock units are the Denver and Arapahoe Formations of the Dawson Group of Upper Cretaceous-Paleocene age. These units have a gentle regional dip to the southeast toward the axis of the syncline. The Denver Formation is younger and

overlies the Arapahoe Formation but the contact between these two units is reported to be transitional and is somewhat uncertain in the arsenal area. Studies by WES (1980) indicate that the Denver Formation is 250 to 400 feet thick in the vicinity of the North Boundary, and therefore, this formation is the only bedrock unit of concern for this study. All further references to bedrock in this report and design drawings refer to the Denver Formation.

c. The Denver Formation is of probable Paleocene age consisting of sequences of deltaic deposits. The depositional environment resulted in deposition of a predominance of fine grained materials rich in organic matter. Lignite seams have been reported nearby and fragments of lignite were encountered in boreholes during this study. Interbedded with the fine grained sediments are lenticular sands and silty sands that apparently represent stream channel deposits that were probably deposited in meandering channels and adjacent portions of flood plains.

d. The lenticular sands of the Denver Formation constitute important aquifer zones in the Denver Basin and yield water to domestic, municipal and industrial wells (along with the Arapahoe Formation). Individual sand beds are lens shaped in cross section but may extend for long distances along sinuous channels. Interweaving of these channels provides good regional lateral interconnection by occasional overlapping of channel deposits. Thickening with vertical overlapping or stacking provides good vertical interconnection over wide areas although this vertical interconnection may be poor at a given location. As a result, individual sand beds by themselves are not important aquifers, but rather groups of sand beds act

as aquifer zones that respond or act much as a single aquifer. This condition is typical of the major ground water basins of much of the Western U.S. and the Atlantic and Gulf coastal plains where they are composed of deep alluvial fill.

e. Well drillers familiar with the Denver Basin generally indicate that the shallower Denver Sands yield less water to wells than deeper Denver and Arapahoe sands, suggesting that sands are less permeable or less prevalent in the upper (250 feet) part of the section. This generalization could be true because of weathering as well as the presence of more coarse facies deeper in the section. The old erosional surface of the Denver Formation went through a long period of erosion and dessication during most of the Tertiary Period which could have resulted in reduction of permeabilities through chemical deterioration of sand grains.

f. Overlying the Denver Formation is an irregular, thin veneer of Quaternary surficial materials that resulted from eolian and stream deposition. The eolian soils overlie the stream deposits, but to our knowledge have not been well defined. They are apparent as sandy and silty soils in the vicinity of Basin F. The stream fluvial deposits represent ancient stream valleys of the South Fork Platte River drainage system. These deposits underlie areas along presently active drainages such as First Creek and occur as terrace deposits in areas such as between Basin F and the North Boundary. In other areas these deposits are absent. These deposits are incised as generally broad but irregular channels into the Denver Formation. Sands with some gravels predominate in or near the deeper channels with a tendency for accumulations of predominately silts and clays near the margins. Also, finer grained materials tend to be

present in the upper portion of these deposits because more recent deposition has resulted from smaller streams with less load capacity than during the initial stages of deposition. The sands and gravels consist of crystalline rocks indicating a source in the Front Range of the Rocky Mountains to the west.

g. The combined alluvial deposits vary greatly in thickness, from 0 to more than 50 feet thick. At the North Boundary the alluvium averages and the saturated on the order of 20 feet thick. Much of these deposits are not saturated and the saturated thickness varies from 0 to a maximum of 30 feet in the North Boundary area. Beneath some areas of other parts of the arsenal the saturated thickness of these deposits is considerably greater. Alluvial deposits are often referred to as the alluvial aquifer or upper aquifer.

Regional studies by Geraghty and Miller of the ground water flow system indicate a general north to northwesterly flow angling toward the South Fork Platte River. The Denver Formation and the alluvial deposits act together (interact) in transmitting flows and are both part of the same flow system. Flow in the Denver Formation is both confined and unconfined and in the alluvium it is generally unconfined but may be locally semiconfined. Potentiometric levels in both units generally correspond rather closely with a tendency for levels in the Denver Formation to be slightly lower. Locally potentiometric levels between may vary greatly due to locally imposed stresses such as heavy pumping from one of the units or local recharge. For example, Geraghty and Miller show a relatively deep

Colorado. This indicates overdraft by pumping more than the flow through this part of the system in this area of this formation, but it also demonstrates the technical feasibility of lowering potentiometric levels in a geologically complex unit, thus creating a hydraulic barrier to natural flow.

h. Even though flow through both geologic units is part of one system, there are significant differences that can be used to advantage in developing pollution containment systems. In general, the alluvial aquifer is much more permeable than sands or other materials in the Denver Formation (by more than two orders of magnitude at the North Boundary). Where present, the alluvium will transmit a much greater percentage of the flow and thus contaminants. This is fortunate in that more options are available for intercepting this flow at generally less cost and it is easier to define and analyze in many respects. The confined flow of ground water in the Denver Formation locally permits separation of containment methods. Confined aquifers with their small storage coefficients, develop larger pumping troughs for the same pumping rate and permit more selective containment because of confining layers. The pumping depression will continue to expand with time until leakage equals pumpage. Also, in lenticular beds hydraulic boundaries created by pinching out of beds accelerates at least locally the development of a pumping depression.

2. Alluvial Aquifer.

a. At the North Boundary, it is reasonable to separate the regional flow system into two subsystems based on geology. The Quaternary Alluvium in this area is predominantly underlain by clay-shales or silt-

stones of the Denver Formation which form a permeability barrier. This barrier is not continuous because there are many subcrops of Denver Sands in direct contact with highly permeable alluvial deposits. However, permeability differences are so great that the two subsystems can be treated separately without introducing substantial errors in ground water flow due to leakage between units.

b. The alluvial deposits near the North Boundary consist of channelized fluvial deposits consisting of clays, silts, sand, and some gravel. Sands with some gravels predominate and probably compose more than half the volume of allufial fill. These coarse grained materials are concentrated primarily in the lower half of the section with the finer grained materials occurring primarily in the upper half of the section and along the margins of the alluvial area.

c. As mentioned previously, the fluvial deposits are probably related to an ancestral South Fork Platte River and are at least in part, terrace deposits left at higher elevations after continued down cutting by this stream. This is apparent in that the primary channel deposits trend from Basin F to the North Boundary rather than along the alluvial valley of First Creek further east. Contours on the base of the alluvial deposits (bedrock contours) confirm this premise and indicate that the First Creek valley was a tributary to this main ancestral channel. These channels converge about 2000 feet south of the proposed barrier alinement and the main channel crosses the boundary between the present channel of First Creek and the bog. There are smaller subsidiary channels incised into bedrock near the bog area, at the east end of the existing barrier and west of the existing barrier a few hundred feet.

d. The bulk of the alluvial materials are low density, unconsolidated sediments. However, there are irregular zones of cemented sands within the unit. These sandstones occur predominantly from the east end of the bog to the west end of the existing pilot barrier. Their extent north and south is unknown and they can occur in any area in the vicinity of the North Boundary within the alluvial unit. They are weakly to moderately cemented with calcite and silica (?) and are friable. Their areal extent and thickness is extremely variable. At Well 1032 nearly all of the saturated sands are cemented, whereas 70 feet away at Well 1031 cemented sands were not detected and, if present, are in thin stringers a few inches thick. Thickness of cemented zones may vary from about 10 feet to a few inches. Cemented sand zones will make excavation of the slurry trench more difficult and also affect distribution of hydraulic conductivities through the alluvial flow system. The cemented sands are described in logs of boreholes and show on design profiles. Figure VI-19 shows a more generalized profile of the alluvial unit along the slurry cutoff wall alinement (cemented zones not shown).

e. The vast majority of ground water flow through the upper 100 feet or more of the combined alluvial and Denver units occurs in the alluvial aquifer. Although the average saturated thickness of the alluvial aquifer at the barrier alinement is less than 15 feet, the average hydraulic conductivities of this unit are probably 1000 times greater than the average hydraulic conductivity of the Denver Formation. The alluvial aquifer probably has an average hydraulic conductivity at least 100 times

the average hydraulic conductivity of sand lenses within the Denver Formation according to field tests. Therefore, it can be seen that about 99 percent of the upper 100 feet of the system flow across the proposed North Boundary containment facility site, is concentrated in the alluvial aquifer. Even if the average hydraulic conductivity of the alluvial aquifer is only 100 times more permeable than the entire Denver Formation, more than 90 percent of the system flow would be concentrated in the alluvial aquifer. Therefore, it is obviously much more important to contain contaminated flows in the alluvial aquifer as opposed to flow through the Denver Formation. Additionally, contaminant levels are much higher in the alluvial aquifer since this is the flow path of least resistance for transport of contaminants from surface sources. These are the reasons that emphasis has been placed on analyses and design of containment facilities for flow in the alluvial aquifer.

f. Flow paths in the alluvial aquifer converge at the North Boundary. The western flow path passes beneath the eastern part of Basin F and trends northeasterly to the North Boundary. The eastern flow path has a northerly trend along First Creek. After these flow paths cross the boundary, they split into north and northwesterly trends.

g. Contaminants are concentrated in irregular plumes primarily in the western flow path. Most of the contaminants are concentrated in the alluvial aquifer with lesser contaminant levels detected in the Denver Sands. Leakage from Basin F is one source of contaminants; however, other basins, pipelines, and the sewage lagoon are additional suspected sources.

3. <u>Denver Formation</u>.

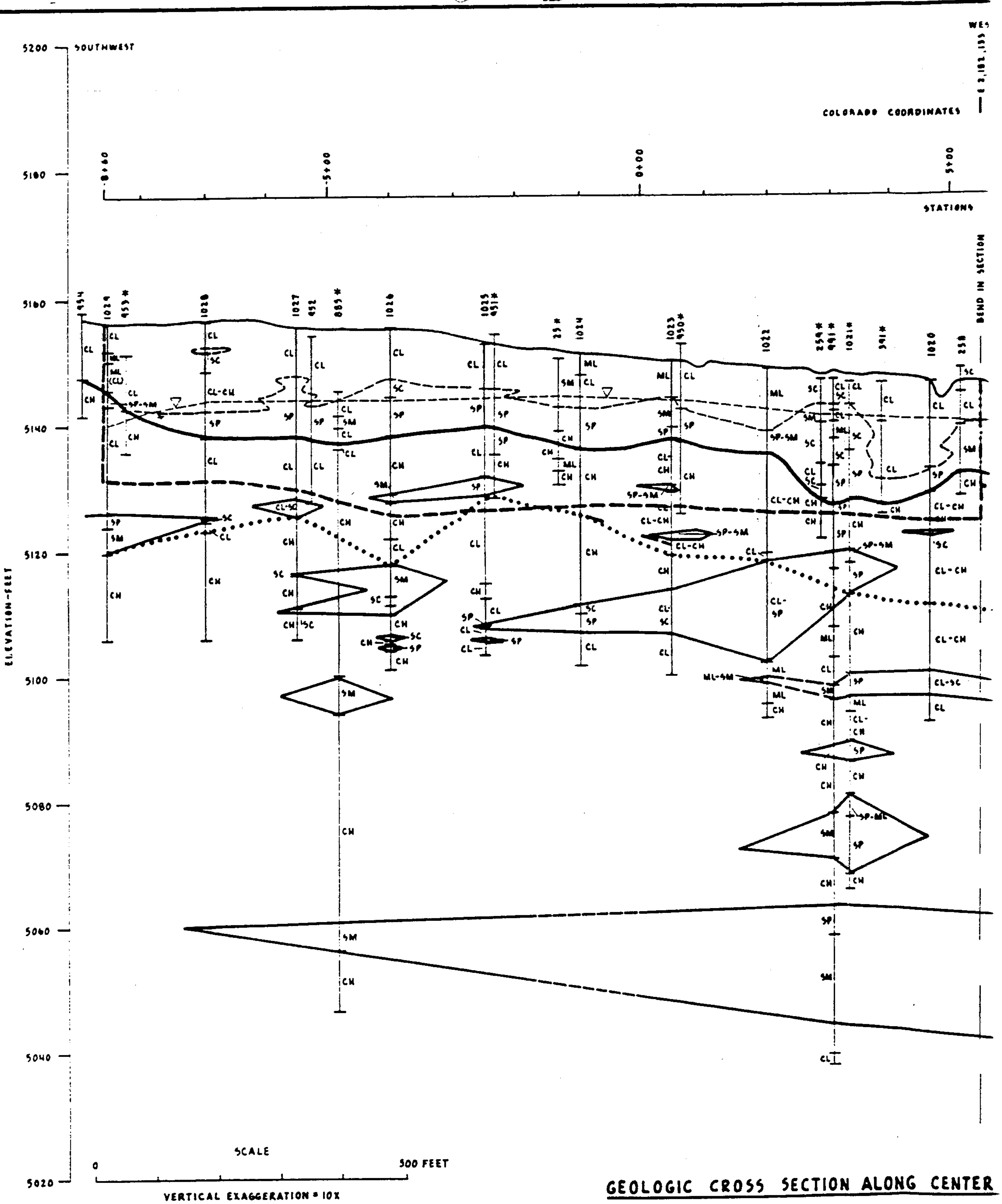
a. The Denver Formation underlying the alluvial aquifer consists of relatively dense sediments deposited in a deltaic environment. In the vicinity of the North Boundary fine grained sediments rich in organic material predominate. The coarser grained materials are channelized in beds lenticular in cross section but may extend for long distances, perhaps miles and probably along a meandering path. A cross section of the Denver Formation along the cutoff wall alinement is shown on Plate 1 (in pocket).

b. The predominant rock types are clay shale or claystone and siltstone with lenses of silty sand and sandstone. Along the barrier alinement, these rocks are weathered to depths ranging from 2 to 25 feet below the erosional surface of the formation. Weathering is gradational with color changes from shades of brown in the weathered zone to gray colors in the unweathered materials. This weathering indicates the erosional surface of the Denver Formation has been exposed to air and dessication permitting oxidation and decomposition of mineral constituents. This suggests that the weathered zone, and perhaps deeper was unsaturated during the geologic past, during the Tertiary Period or possibly early Pleistocene.

c. The regional dip of beds is very gentle to the southeast or almost flat because of the close proximity of the axis of the Denver Basin syncline. Faulting has not been detected at the North Boundary, although faults may be present, but obscured by soil cover. Denver rocks are jointed and fractured in the vicinity of the proposed barrier as observed in sample cores and described in borehole logs. The clay shales or claystones are

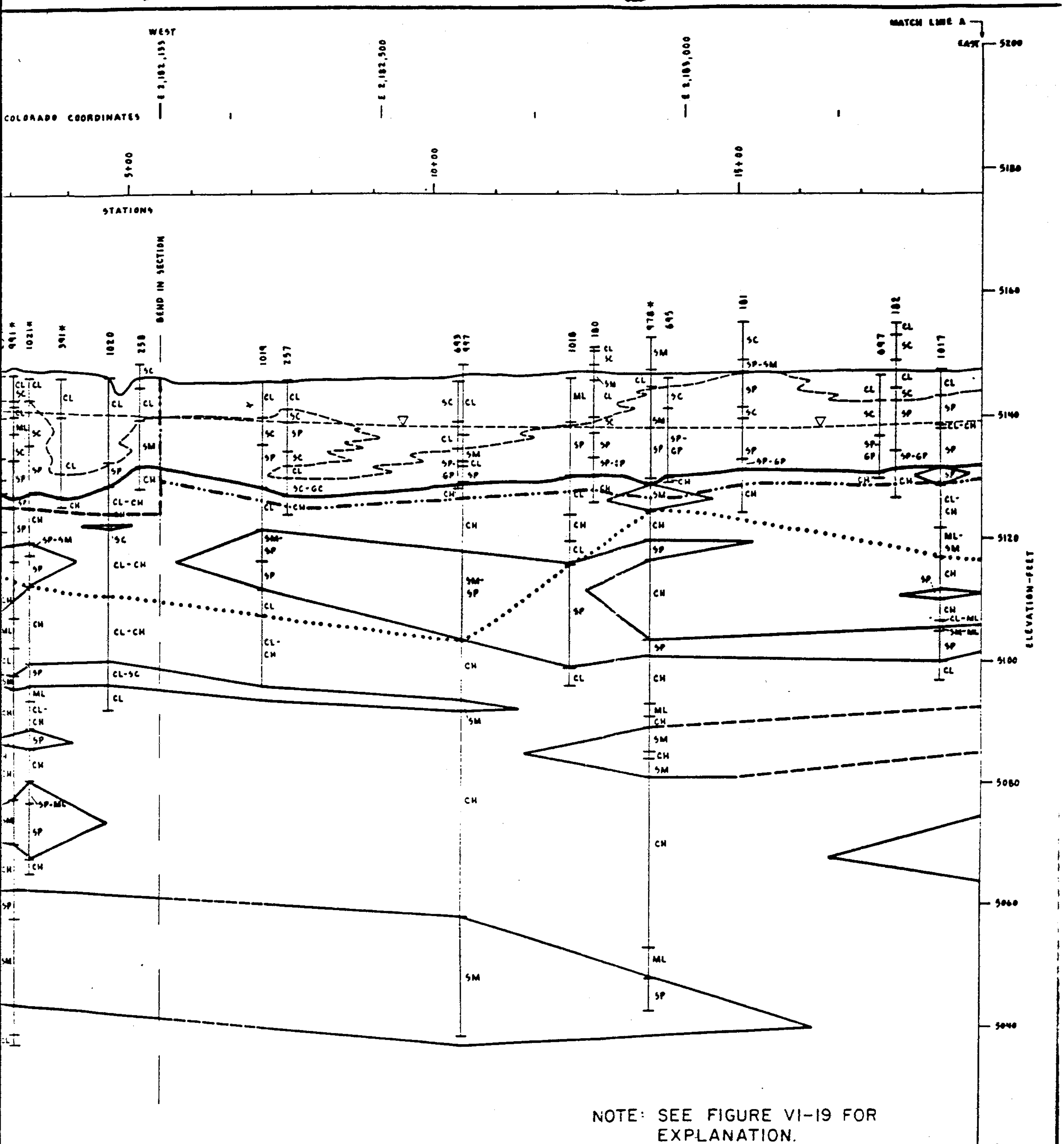
relatively massive and do not exhibit shale partings. They are not fissile. Joints and fractures are probably related to stress relief due to unloading by erosion and perhaps more important, due to dessication resulting in contraction cracks. The upper part of the unit, especially in the weathered zone is often classified as intensely fractured or crushed. This is probably not due to tectonic forces, but is probably related to drying. These materials were probably too dense to form regular mud cracks but instead formed irregular hairline fractures with a close spacing. Stress relief perhaps also played a role in this type of fracturing. Also, more planar and wide space joints are present with some evidence of shearing which suggests tectonic forces and/or stress relief. Iron staining was noted on fracture surfaces which indicates the joints and fractures were open enough to transmit water when the rocks were unsaturated and an oxidizing environment existed. At the present time (and since deposition of the overlying alluvium), the Denver Formation is saturated (except beyond the ends of the proposed barrier). With resaturation of these materials, it is reasonable to expect the clays to expand and contraction cracks to close or partially close, thus reducing their ability to transmit water. This is not meant to imply that fracture permeability does not exist. Most of the water transmitted by the claystones and siltstones both in the weathered and unweathered zone is probably by fractures, but field data indicates the fracture permeability is very low and that fractures are relatively tight which is generally the case in soft clayey rocks of this type. More brittle and fissile shales often transmit substantial amounts of water where stress relief has opened shale partings.

①



GEOLOGIC CROSS SECTION ALONG CENTER

(2)

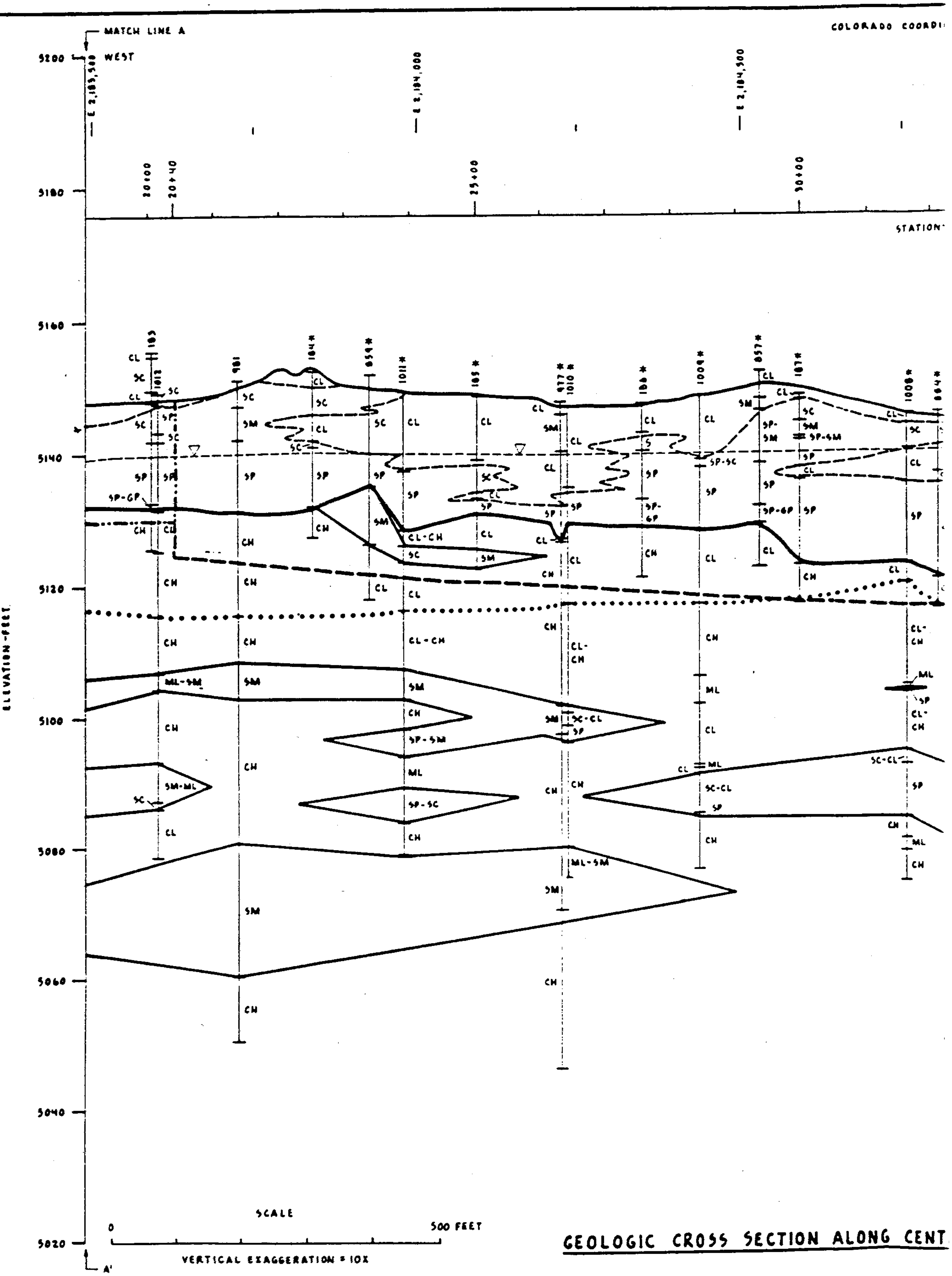


NOTE: SEE FIGURE VI-19 FOR EXPLANATION.

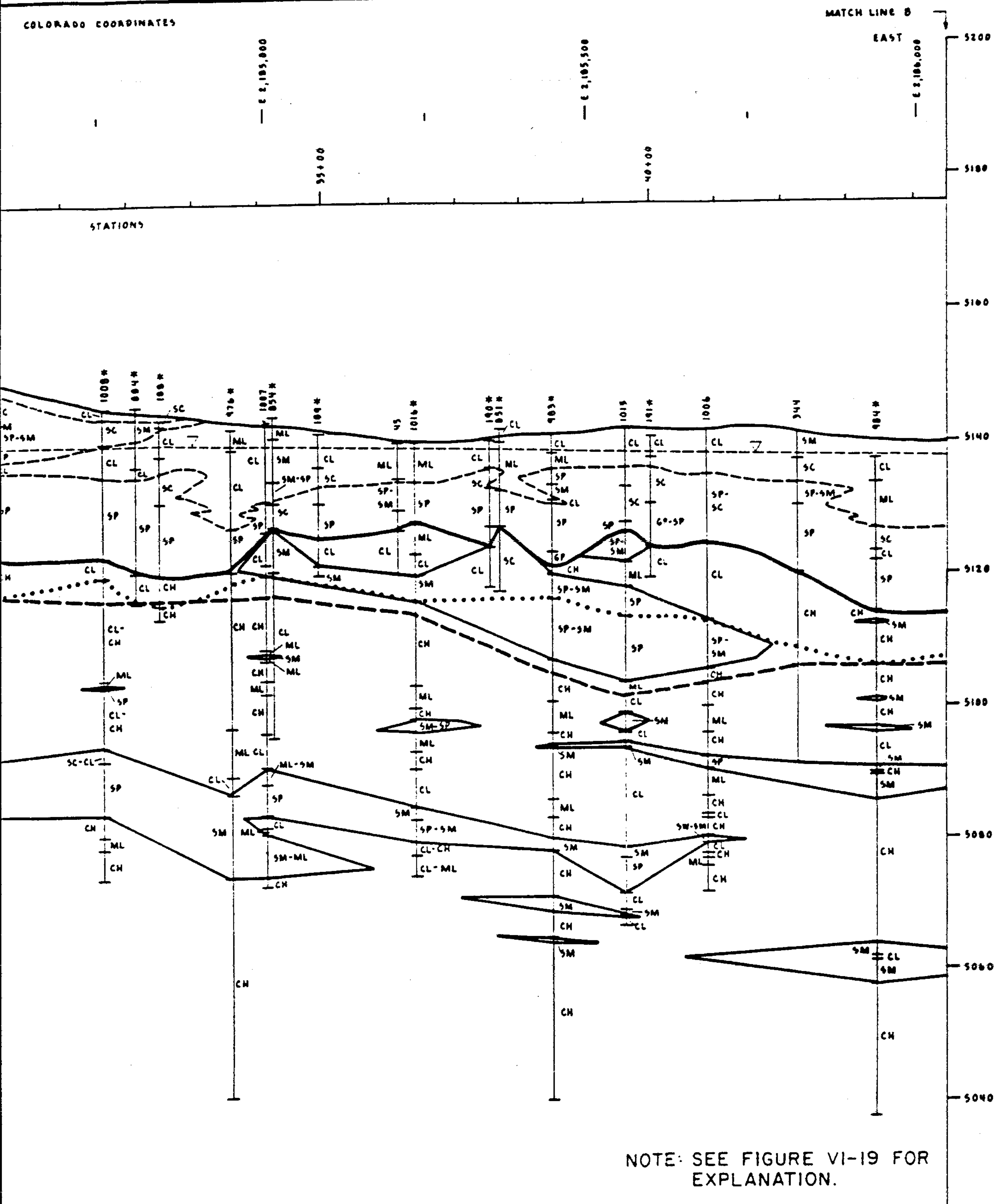
ION ALONG CENTER LINE OF PROPOSED BARRIER

Figure VI-19A

1



GEOLOGIC CROSS SECTION ALONG CENT

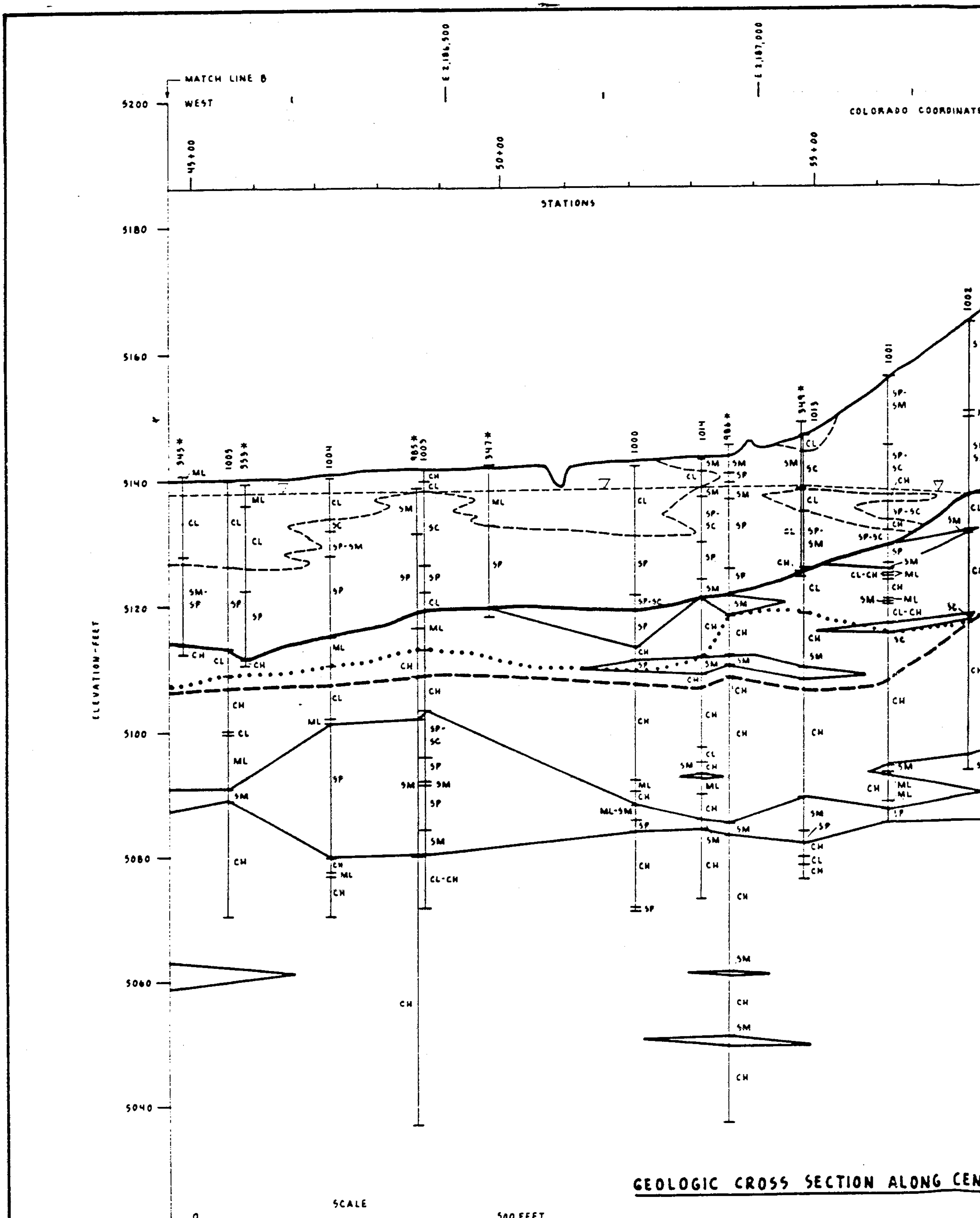


NOTE: SEE FIGURE VI-19 FOR EXPLANATION.

N ALONG CENTER LINE OF PROPOSED BARRIER

Figure VI-19B

(1)

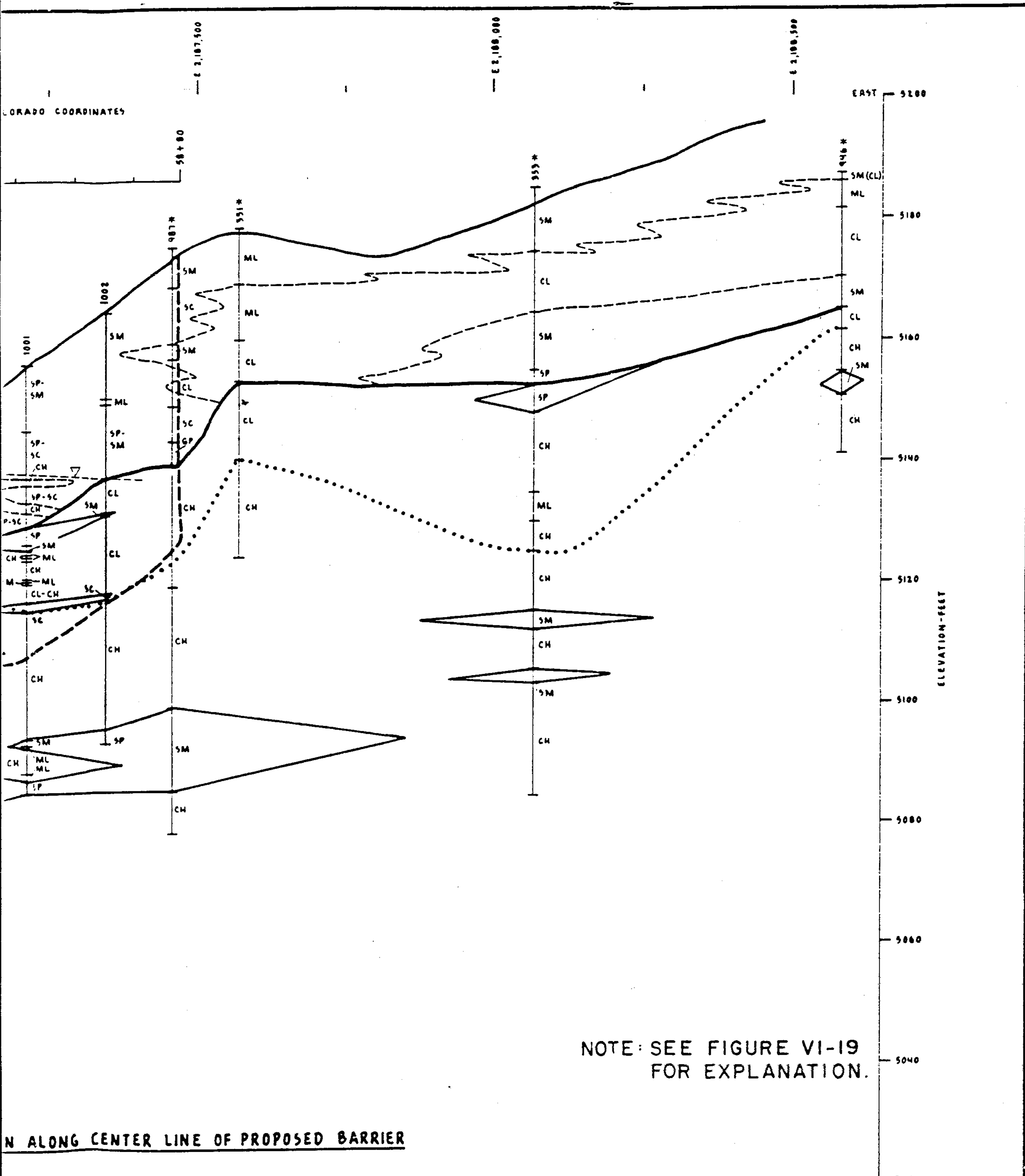


GEOLOGIC CROSS SECTION ALONG CEN

SCALE

0 500 FEET

VERTICAL EXAGGERATION = 10 X



NOTE: SEE FIGURE VI-19 FOR EXPLANATION.

N ALONG CENTER LINE OF PROPOSED BARRIER

Figure VI-19C

d. Field permeability tests indicate hydraulic conductivities of up to 19 feet per year (1.9×10^{-5} cm/sec) in the fractured claystone or clay shale. This was the only test conducted specifically in this type of rock. However, two pump tests were performed, pumping from Denver Sand units and in both cases these sands were highly confined by the overlying claystone beds (see appended data plots and calculation sheets for test Wells 1041 and 1045). A slight amount of leakance was detected in data for the test on Well 1041 which indicated a hydraulic conductivity of about 0.1 foot per year (1×10^{-7} cm/sec) for the confining layer. WES (1980) reports 23 slug tests in Denver Sand beds and in all but two tests, confined aquifer characteristics were reported. The two tests reporting unconfined conditions were regarded as fair to good matches of type curves and could be questioned.

e. Hydraulic conductivities of Denver Sands determined by WES slug tests ranged from about 14,000 feet per year (1.4×10^{-2} cm/sec) to 0.8 feet per year (8×10^{-7} cm/sec) which suggests extreme variations due to cementing, density, and gradation. However, the two pump tests (1041 and 1045) yielded relatively consistent results from two widely separated sands with hydraulic conductivities ranging from 405 to 576 feet per year. The pump tests used observation wells for time drawdown measurements which avoids effects due to well construction and are considered more reliable than slug tests or other in well tests for hydraulic conductivitiy. Nevertheless, there is probably a considerable range in permeability in the Denver Sands especially in the thinner, siltier beds and cemented zones. The larger units are probably more permeable as well as more extensive along their channel axis.

f. The variability of permeability within the Denver Formation both in uncertainties regarding fracture flow and the sand lenses presents some risks regarding interception of contaminants. However, the risks involved are considered to be low because: (1) total flow through this formation is relatively minor and slow; (2) contaminant levels are low; (3) flow through the more permeable sand lenses can be intercepted by wells; (4) there is probably interconnection of sand channels because of their branching and interweaving geometry; and (5) fractures appear to be relatively tight. These deposits can be intercepted with wells by creating a pumping trough and inducing flow to the wells. If fractures are open and extensive enough to transmit significant quantities of water, it is reasonable then to assume that the fractures would drain into the sand lenses that are stressed by pumping. The primary risk for this type of system with highly variable permeabilities is in designing well spacing. However, the well system provides flexibility in that wells can be added as needed and/or pumping rates can be varied based on operational experience. In contrast a full depth cutoff wall has little flexibility and wells would still be needed to intercept flows. If large open fractures are present at the base of the cutoff wall, the bentonite slurry would tend to penetrate and seal them at least partially, if they are large enough to transmit relatively large flows. Also, if open fractures are in direct hydraulic connection with the alluvial aquifer, alluvial dewatering wells would intercept at least part of these flows because about the same hydraulic stress inducing flow to the wells would be imposed on the fracture flow as on the alluvial aquifer. On the recharge side of the barrier, treated

water would mix and dilute contaminants bypassing the barrier transmitted by shallow fractures. Therefore, the risks involved due to the relative geologic complexities of the Denver Formation are minimal. The extensive and relatively elaborate monitoring program should at least detect any serious problems that may develop. Also, ground water velocities are so slow in the Denver Formation that abundant time will be available to activate remedial actions if serious defects are detected.

g. Flow in the Denver Formation is in essentially the same direction as in the alluvial aquifer. Potentiometric levels are slightly lower overall, resulting in a downward component of flow. Gradients in the two units are generally parallel but may be slightly steeper at the North Boundary in the Denver Formation than in the alluvial aquifer due to a regional flow net effect. To be conservative a slightly steeper gradient was assumed for flow calculations. Data are not available to confirm this precisely because most deep observation wells are alined perpendicular to the direction of flow which is to the north at the boundary.

h. Contaminant levels within the Denver Formation are very low except for sands in direct contact with the alluvial aquifer. However, contaminants have been detected in various deeper Denver Sands. The low levels of contaminants that are present are the result of the slight downward flow component. With continued development of monitoring data coupled with more experience with sampling and analyses, it is becoming somewhat questionable if any of the deeper Denver Sands are contaminated to levels above drinking water standards. It is particularly significant that the relatively shallow sand unit beneath the existing pilot barrier is not

contaminated above drinking water standards for DIMP, DBCP, DCPD and F. This sand underlies the most highly contaminated part of the alluvial aquifer. The confining layer of weathered clay-shale is only 6 to 14 feet thick separating this sand from the alluvial aquifer. This sand was heavily stressed for 24 hours by pumping yet contaminant levels remained below drinking water standards for the control consituents. If open fractures existed in the confining layer, more contaminants would probably have been induced into the test well.

C. HYDRAULIC ANALYSIS - ALLUVIAL AQUIFER.

1. Requirements and Criteria.

a. Alluvial aquifer system flows across the North Boundary must be determined to estimate dewatering and recharge rates and to estimate contaminant fluxes. The distribution of system flows must be estimated with reasonable accuracy so that dewatering and recharge rates can be distributed with a minimum amount of disturbance of the natural flow system.

b. A total of 35 dewatering wells were selected (including the six existing wells) based largely on judgment and experience with the pilot facility.

c. Dewatering rates and distribution of pumping rates must be sufficient to prevent flooding over the top of the cutoff wall.

d. Recharge wells must be spaced so that recharge rates re-establish the alluvial flow system offpost. Also, each well must be capable of receiving the distributed rate for each location without surface flooding.

e. Design of the North Boundary barrier system requires a detailed knowledge of flow through the alluvial aquifer in the project vicinity to meet criteria for interception of selected flow components. A digital simulation model of the geohydrologic system provides the best tool for defining total system flows as well as flows through any selected zone. It also provides a means of evaluating aquifer hydraulic responses to pumping and recharge wells as well as breakdown scenarios.

2. Hydraulic Model Development.

a. Simulation of the geohydrologic system in the vicinity of the North Boundary was accomplished by construction of a digital model as proposed by Trescott, Pinder and Larson (USGS, 1976). This finite-difference model simulates the aquifer's response to stresses in two dimensions and enables accurate representation of complex boundary conditions and system heterogeneities by approximating the partial differential equation governing ground water flow with finite differences for the derivatives at numerous distinct nodes representing the aquifer. The resulting system of algebraic equations (one for each node in the system) is solved using a highly efficient technique known as the "strongly implicit procedure". For the North Boundary model, the finite-difference grid contains 2,958 cells (29 rows by 102 columns) as shown on Figure VI-1. Each cell has a node at its center. The cells are 100 feet by 100 feet near the slurry cutoff wall and are up to 100 feet by 500 feet to the north and to the south. Given a distinct system geometry, aquifer characteristics, boundary conditions, and initial water levels, the model solves for the average hydraulic heads at each node.

FINITE DIFFERENCE GRID

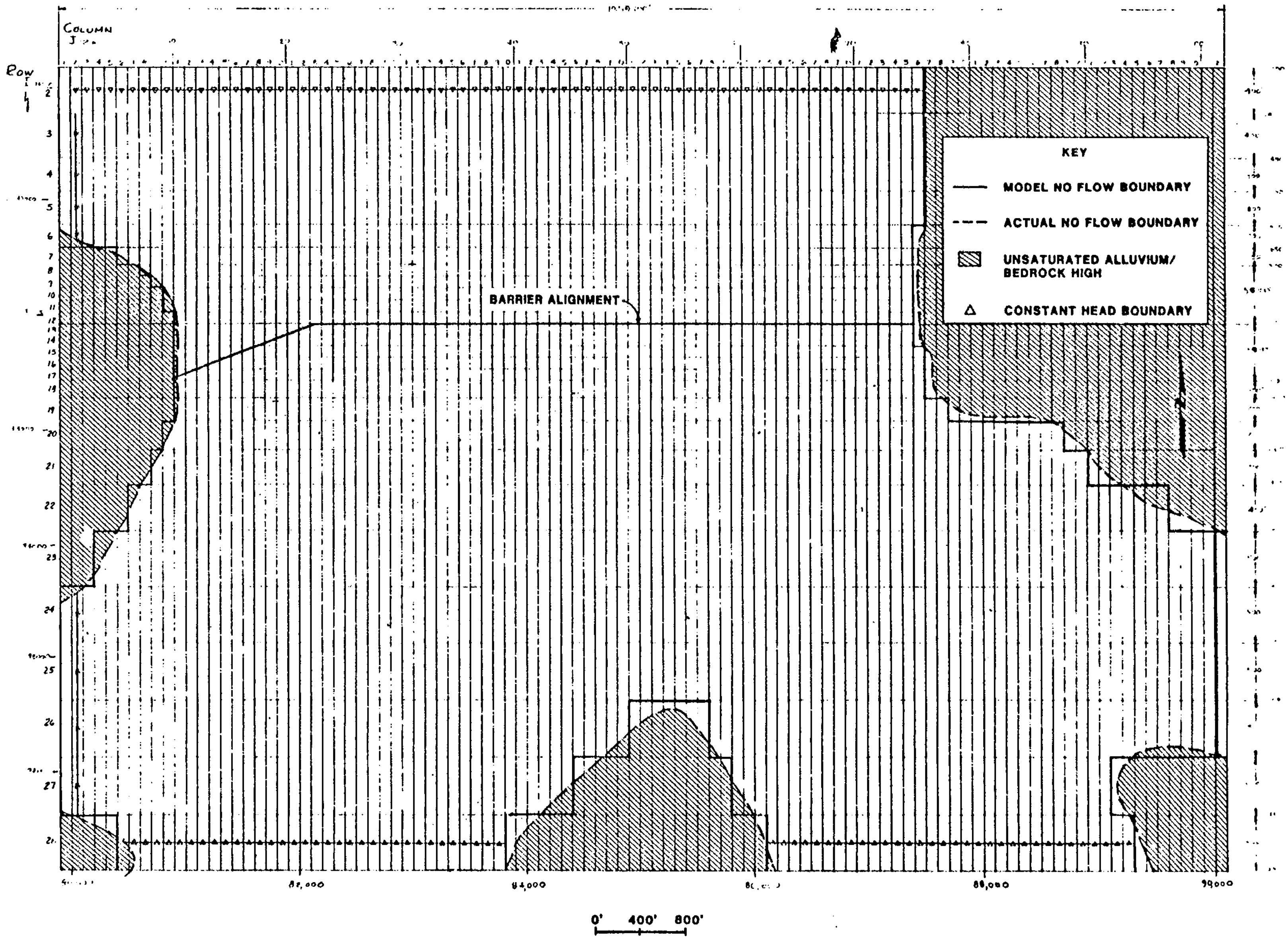


Figure VI-1

b. Boundary conditions modeled consist of no-flow boundaries and constant head boundaries. No-flow boundaries are represented by specifying a permeability of zero at the nodes outside the boundary. The harmonic mean of the permeability at the cell boundary is zero, and as a result there is no flow across the boundary. A boundary condition of this type was used where alluvium is absent or unsaturated and along the small basin to the southeast. The bedrock high areas are believed to be much less permeable than the alluvial aquifer, and their treatment as no-flow areas is therefore justified. Constant head boundaries were assumed where no physical boundaries existed. Along these boundaries, heads were fixed at "steady state" values which were based upon best available water level data. These fixed head boundaries will not influence model results when hydraulic stresses are located far from these boundaries and the simulation period is short.

c. The finite-difference model assumes the aquifer may be represented as a two dimensional, isotropic, heterogeneous unconfined system with a nonleaky underlying layer. In other words, it was assumed that the Denver Formation is impermeable. This is a valid assumption, for modeling purposes because of the extremely low permeability of the Denver Formation. Within the model area, recharge from precipitation is negligible and evapotranspiration is assumed to be negligible. There are evapotranspiration losses in the bog area mainly downgradient from the barrier, but the losses are estimated to be less than 5 percent of the alluvial aquifer flow.

d. Computation of in-well hydraulic heads at the pumping and recharge wells was accomplished by employing a form of the Thiem equation. This is necesary for extrapolating from the average hydraulic head for each cell to the head at the effective well radius (8 inches for pumping wells and 1 foot for recharge wells.) This approximation is based on the following assumptions: (1) flow takes place within a square well block (grid cell in three dimensions) and can be described by a steady state equation with no external sources; (2) the aquifer is isotropic and homogeneous within the well block; (3) only one well is in the well block and it is fully penetrating; (4) flow is laminar; and (5) well loss is negligible. For design purposes, model produced drawdowns were increased by 10 percent to account for well friction losses. Extremely low friction losses are anticipated because of the large open area of screens and low pumping rates.

e. Calibration of the finite-difference model consists of distributing permeabilities throughout the nodal system so that model simulated water levels match observed water levels that are reasonably near a steady state. This is necessary because inflows and outflows to the system are unknown, but are assumed to be equal because recharge and evapotranspiration within the modeled area are negligible. The finite-difference model requires that an average hydraulic conductivity, specific yield, bedrock elevation, and water level be specified at each node. The saturated thickness of the alluvial aquifer was determined by the elevation difference between water level contours shown on Figure VI-2 and bedrock

GROUNDWATER ELEVATIONS

SPRING 1979

NORTH BOUNDARY AREA - RMA

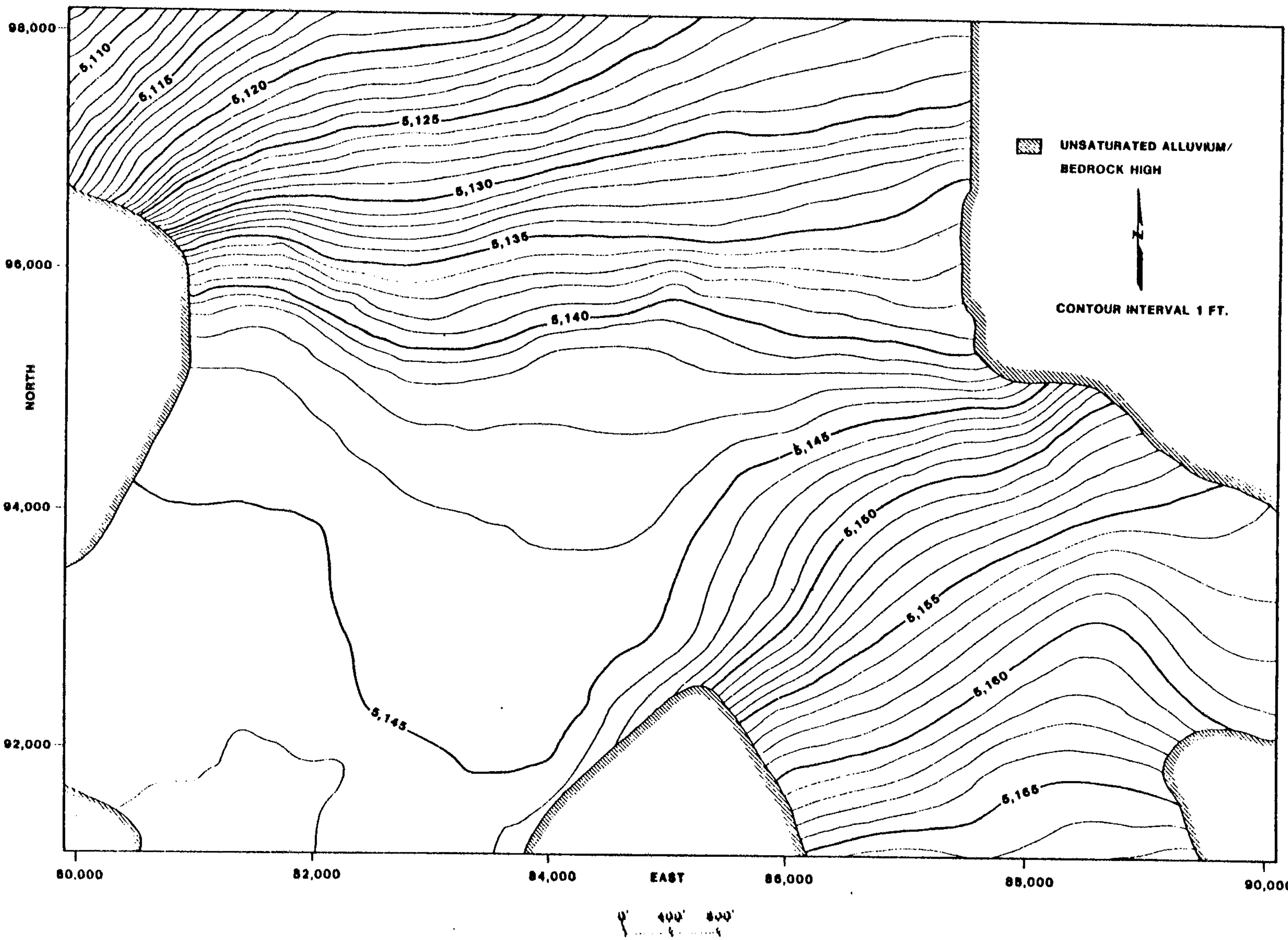


Figure VI—2

contours shown on Figure VI-3. Saturated thickness is shown on Figure VI-4. Water level contours used are based on spring 1979 water level measurements. These water levels were compared with other historic water level measurements and were judged to be a resonably good representation of steady state conditions. Hydraulic conductivities and specific yields are based on six pump tests performed by WES and two new pump tests performed by ESA in 1980. Summaries of pump test results are shown in Table VI-1A and Table VI-1B and calculation sheets and field data plots are appended for ESA pump tests. Data from WES test Wells 2 and 3 were not used because of variable pumping rates. Calculated specific yields ranged from 0.35 to 0.01 and a vertically averaged value of 0.1 was used to best represent conditions near the dewatering and recharge wells. Specific yield is not an important factor in calibration of the model because it is not a function of steady state head distribution. Additionally, specific capacity data from the pilot barrier dewatering wells were used to check modeled hydraulic conductivities in the vicinity of those wells. As a result, calibration of the model is dependent on the hydraulic conductivities assigned each node and the accuracy of the modeled flows is, therefore, dependent on the validity of hydraulic conductivities determined from pump test data. The modeling technique forces fluxes throughout the system to balance so that hydraulic conductivities are correct relative to cells where pump test data were obtained when calibrated to observed steady state water levels.

f. The finite-difference model was calibrated using the inverse method. This method included the following steps:

BEDROCK CONTOUR MAP

NORTH BOUNDARY AREA - RMA

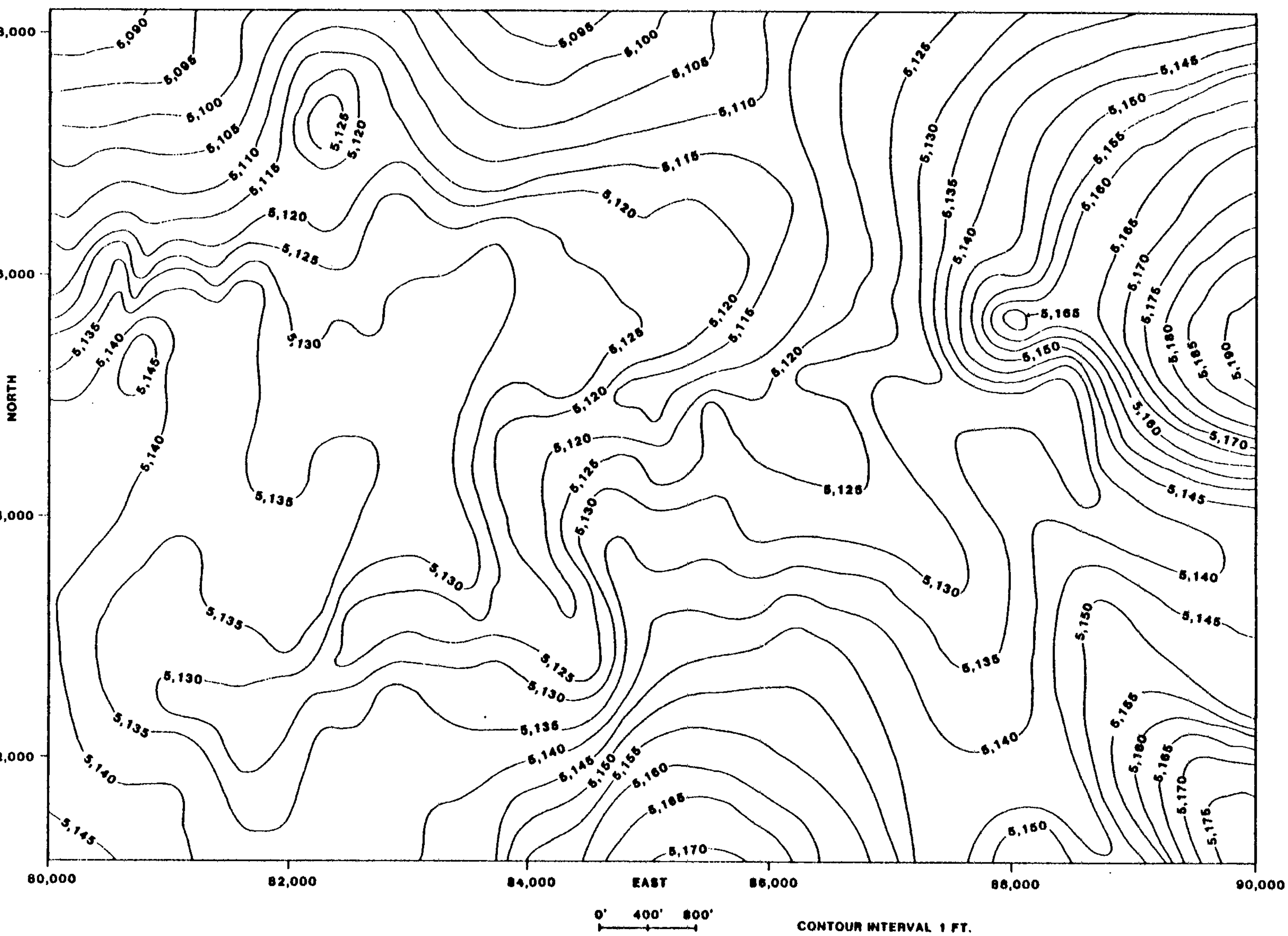


Figure VI-3

SATURATED THICKNESS OF ALLUVIAL AQUIFER

NORTH BOUNDARY AREA - RMA

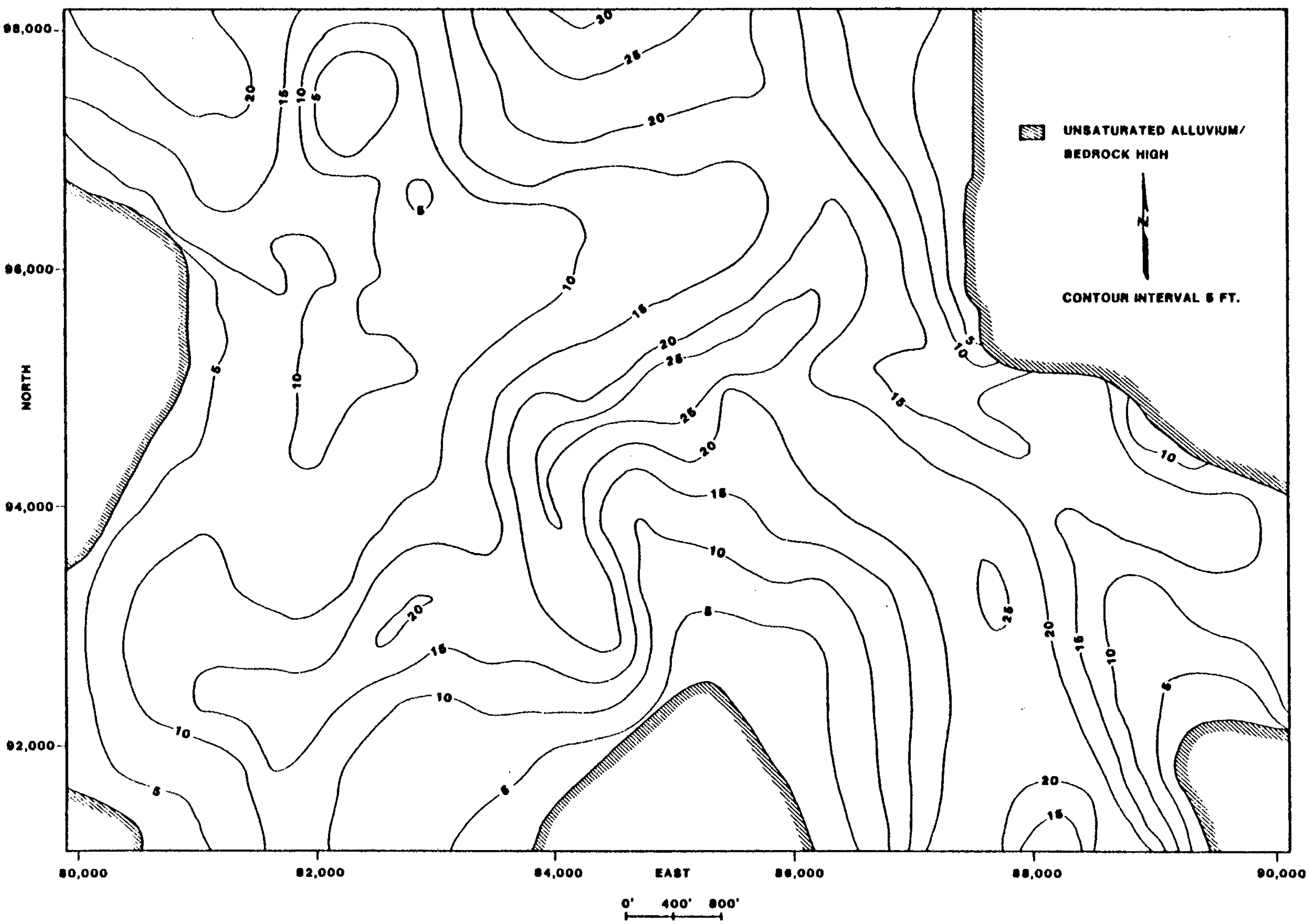


Figure VI-4

TABLE VI-1A

SUMMARY

of

PUMP TEST RESULTS

in

ALLUVIUM, ROCKY MOUNTAIN ARSENAL

Test No.	Obs. Well	T (gpd/ft)	S_y
1032-1	1031	19,864	0.003
	1030	23,837	0.14
1032-2	1030	20,342	0.02
	1031	20,342	0.0027
Approx. Average for	1032	21,096	0.0414
1036-2	1033	18,794	0.01

NOTES:

Average k in vicinity of well 1032 = $\frac{21,096}{17}$ = 1,241 gpd/ft = 60,558 ft/yr

Average k in vicinity of well 1036 = $\frac{18,794}{11}$ = 1,709 gpd/ft = 83,377 ft/yr

T = transmissibility

S_y = specific yield

k = horizontal hydraulic conductivity of alluvium

TABLE VI-1B

SUMMARY OF TRANSMISSIVITY AND PERMEABILITY DATA

Well No.	Avg. Transmissivity (gpd/ft)	*Effective Saturated Thickness (feet)	**Hydraulic Conductivity (gpd/ft)
WES No. 4	25,000	12.05	2,075
VISPI 529	74,000	7.57	9,841
VISPI 345	25,000	11.35	2,203
VISPI 368	41,500	3.5	11,857
VISPI 549	9,550	7.0	1,364
VISPI 548	17,000	7.0	2,429
ESA 1032	21,000	15.6	1,346
ESA 1036	19,000	8.33	2,281

* Effective saturated thickness does not include lays and silts. This saturated thickness is used to calculate hydraulic conductivity of sand and gravel aquifer $\frac{\text{Transmissivity}}{\text{saturated thickness}}$ = hydraulic conductivity.

** These hydraulic conductivities for 1032 and 1036 are different from those shown in Table VI-1A because the effective saturated thickness was used instead of the total saturated thickness used in Table VI-1A.

NOTE: Specific yield values are not shown because they were not used in the model. A uniform value of 0.1 was used for all nodes.

(1) Development of steady state water levels which was accomplished by contouring the best available water level data for 202 observation wells distributed throughout most of the system. Resulting water level contours are shown on Figure VI-2.

(2) Trial values of hydraulic conductivity were estimated based on pump tests between Basin F and the North Boundary. All available pump test data were analyzed using the unconfined type curves of Newman (1975) which are appended with calculation sheets. Initial hydraulic conductivities for the model area were established using a model calibration procedure proposed by Hunt and Wilson (1974), and Day and Hunt (1977).

(3) Using the above data, the analysis was then carried out until a steady state condition was reached.

(4) A comparison of the observed and calculated water levels was then made and the hydraulic conductivities adjusted until a suitable match was obtained between the observed steady state water levels established in (1) and those obtained from the model using adjusted hydraulic conductivities. Resulting model hydraulic conductivities are represented by transmissivity contours shown on Figure VI-5 (transmissivity = hydraulic conductivity times the saturated thickness).

g. After calibration, 98.4 percent of the active nodes were within 2 feet of observed water levels, 96.7 percent were within 1.5 feet

TRANSMISSIVITY CONTOURS

NORTH BOUNDARY AREA - RMA

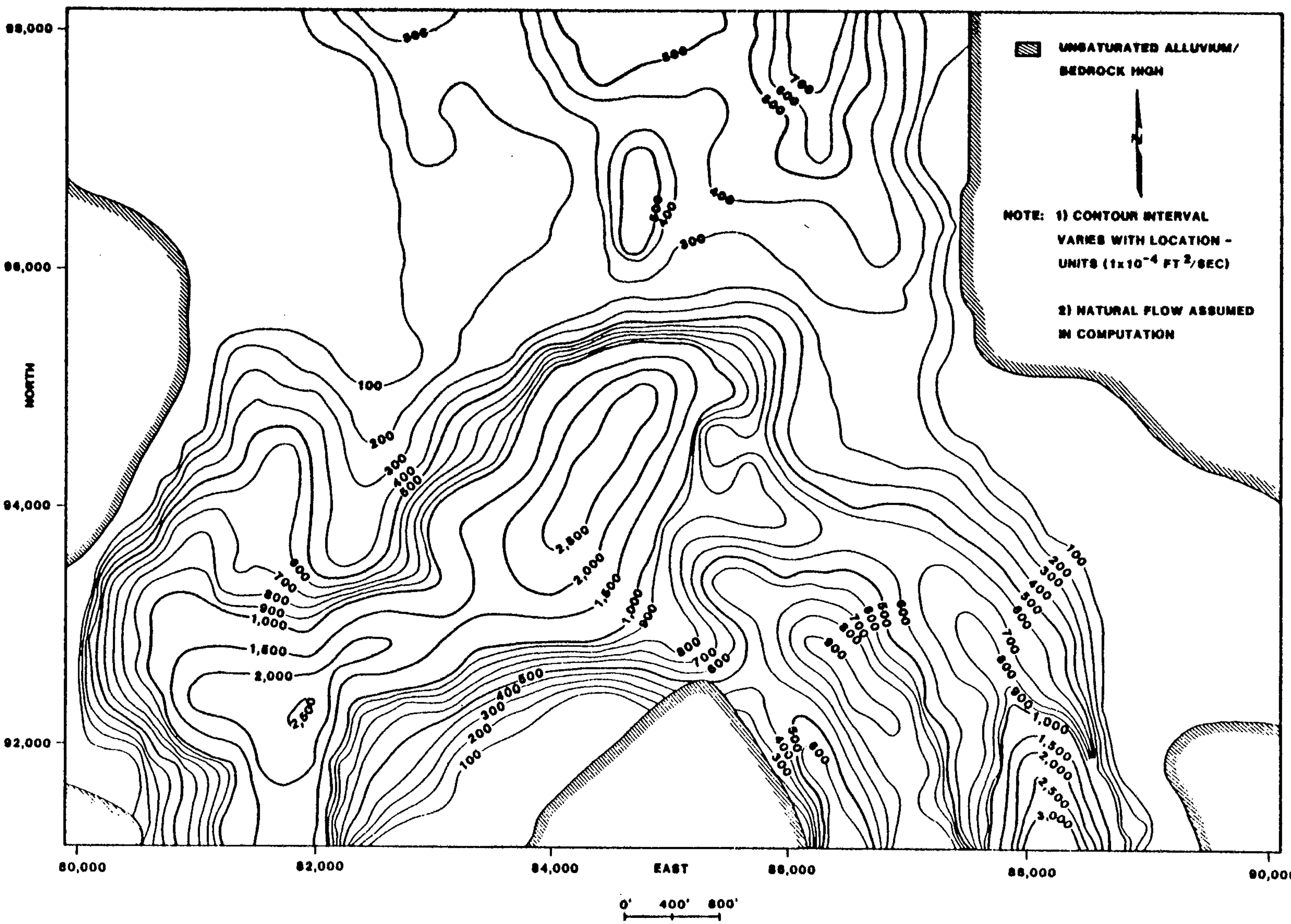


Figure VI-5

and 93.4 percent were within 1 foot. Considering the local seasonal variation and the scarcity of data in some areas, this calibration was judged to be adequate for design purposes. The simulated steady state ground water levels are shown on Figure VI-6.

3. Simulation and Analysis.

a. The natural flow through the system was computed by the model to be 440 gpm. Once the barrier is in place this flow must be captured by dewatering wells. More water will have to be pumped and recharged than 440 gpm because of several factors.

(1) In the long term, pumping will lower ground water levels in the proximity of the dewatering wells and will induce more flow through the system because of the steeper gradients induced by well drawdowns.

(2) At the initiation of pumping, the influence of each well is small and flow will bypass the pumping wells causing a rise in ground water levels near the barrier. If the wells are extracting flow equal to the natural flow rate, some water would come from storage upstream of the dewatering wells. On the downstream side of the dewatering wells (near the cutoff wall), flowing water would accumulate. To prevent this rise in ground water levels during early time, pumping must capture the natural flow plus water taken from storage.

(3) It is desirable to lower water levels in the aquifer between the pump wells and the cutoff wall because in the event of failure of dewatering wells, the dewatered zone serves as a

GROUNDWATER ELEVATIONS

SIMULATED STEADY STATE

NORTH BOUNDARY AREA - RMA

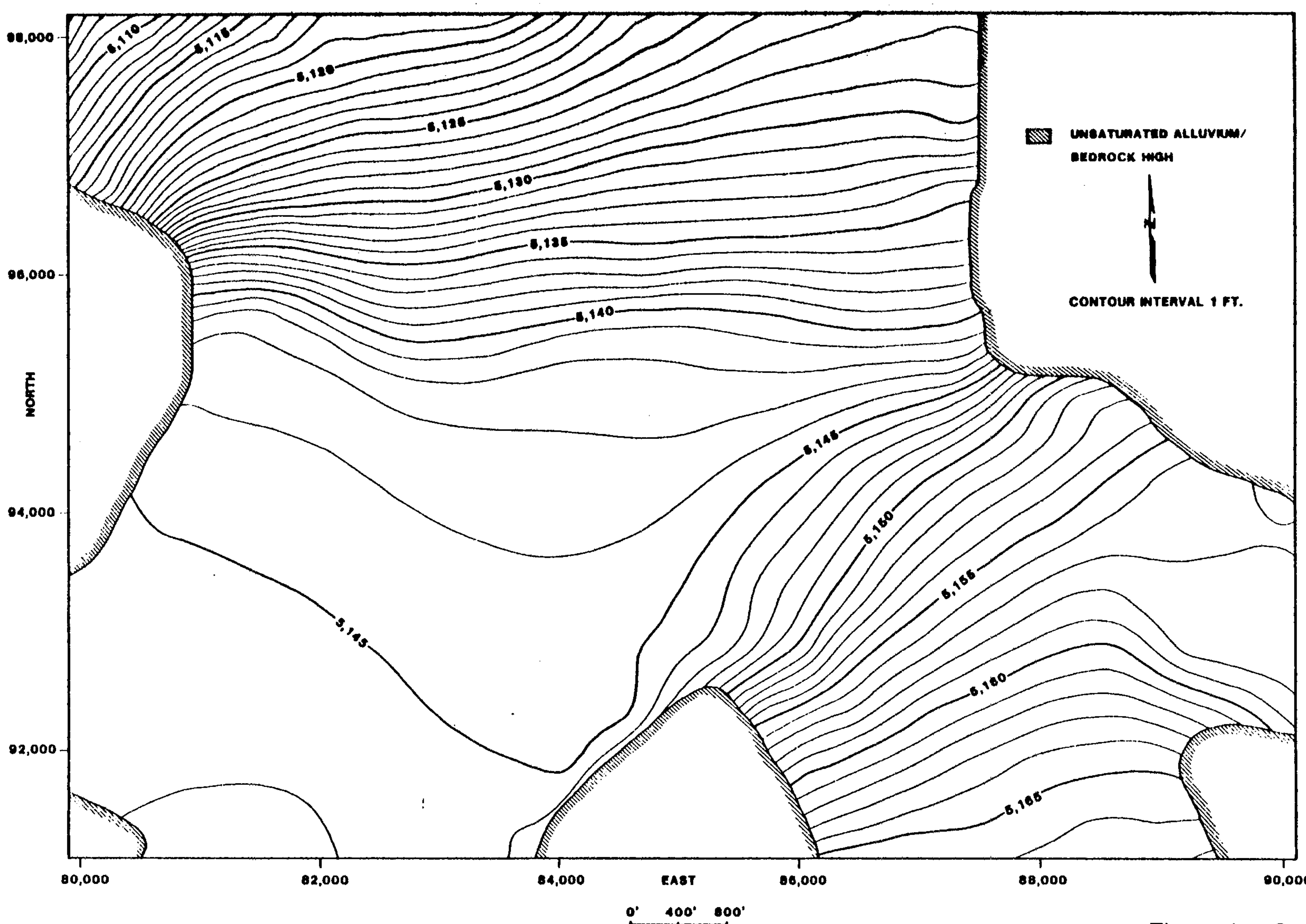


Figure VI-6

storage buffer against flooding. To create this ground water storage buffer, pumping must exceed natural flow rates.

(4) While system flows were computed as precisely as possible, both the total system flow rate and local flow rates can be in error. As a precaution against flooding, a safety factor of $\pm$ 50 percent is included in design pumping rates.

b. Design dewatering and recharge rates were based on natural flows plus 10 percent. Natural flows were calculated for 100-foot segments (each cell) along the barrier. The water was distributed to each dewatering and recharge well based on its likely zone of influence. The 10 percent additional pumping was found to be sufficient to prevent significant flooding based on the simulation model. It should be noted that the design pumping rates are a best estimate based on interpretation of pump test data. Since these values may have to be adjusted during operation, each pumping well is designed to have a pumping range of $\pm$ 50 percent of its design value. This design flexibility also will allow for an increase in individual pumping rates to compensate for individual well shutdowns for maintenance or failure.

c. Figure VI-7 shows the simulated steady state ground water surface resulting from the pumping and recharge system. Steady state conditions should be reached in approximately from four and one-half years assuming flow into the modeled area remains reasonably constant.

d. Figure VI-8 shows ground water profiles at various simulated times, located 50 feet south of the cutoff wall. This figure shows the

STEADY STATE GROUNDWATER ELEVATIONS

SIMULATION OF DEWATERING AND RECHARGE WELL OPERATION

NORTH BOUNDARY AREA - RMA

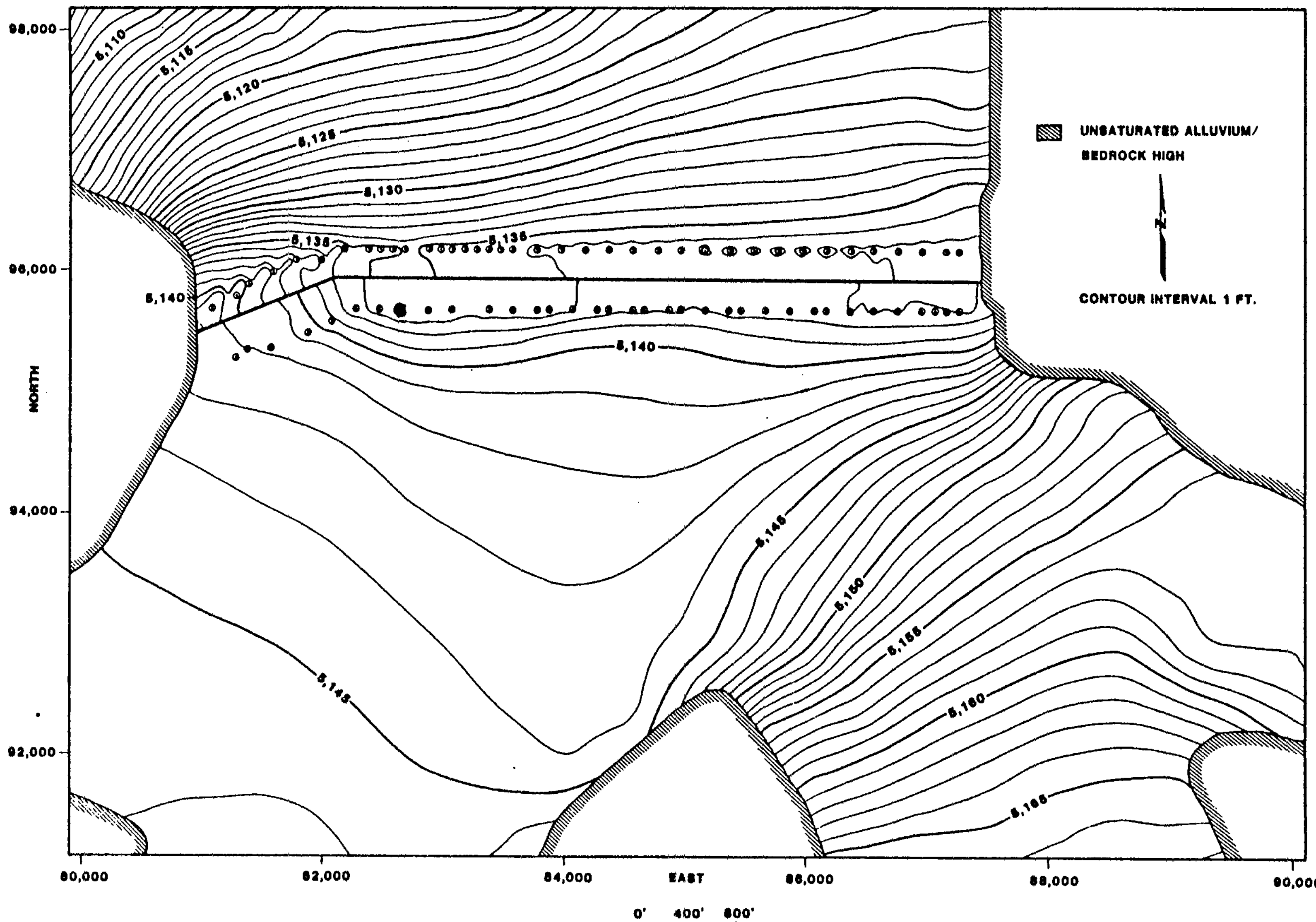


Figure VI-7

sequence of water level changes that will occur during the first few years of operation. These stages are summarized below.

(1) Natural flow conditions are assumed to exist when the cutoff wall is first constructed. Instantaneous construction and pumping is assumed for modeling purposes. In practice, dewatering wells will be in operation prior to start of construction of the cutoff wall.

(2) Pumping begins and water levels rise near the cutoff wall because of the limited influence of the pumping wells. Water is removed from storage upstream of the pumping wells and some of the system flow avoids capture by flowing between the wells. This stage should be carefully monitored. Water levels are expected to rise, but not high enough to cause flooding. If water levels rise higher or more rapidly than indicated in the profiles then pumping must be increased or flooding will occur. There is a lag time between initiation of pumping, significant water level changes, and water level control near the barrier. Therefore, the monitoring of water levels at the cutoff wall will be a key indicator of the need for pump changes.

(3) Water levels have peaked and now decline. Water coming from storage upstream of the pumping wells has diminished. The zone between the wells and barrier begins to dewater creating a storage buffer. Water levels (50 feet south of the cutoff wall) fall below presystem levels after about one year.

(4) Water levels have stabilized and minimal adjustments to the system are required.

e. The recharge system is coupled to the discharge system in that total flow rates must be the same. Design recharge rates have been established. If these rates are altered during operation, care should be taken not to overinject in the flood susceptible zone toward the east, particularly near the existing bog and First Creek.

f. Simulations studies were conducted to view the impact of a total pump system failure once the cutoff wall is in place. Three scenarios were considered.

(1) Total pumping system failure once barrier is in place before pumping ever begins.

(2) Total pumping system failure after 200 days of operation.

(3) Total pumping system failure after 1,500 days of operation.

For each case, flooding occurred after a relatively short period. Figure VI-9 shows the zones where flooding is likely to occur for the scenarios listed above. Some of the zones of flooding shown near the south margin of the map area along First Creek are due to differences between observed and calibrated water levels. Unfortunately, this is where the least accurate water level data exist, and the simulated flood zone is only approximate. However, the flooding simulated near the barrier is relatively accurate.

g. The resulting impacts of flooding are summarized below.

(1) If total pump well failure occurs just after the barrier is in place, flooding after 11 days will occupy over 4,500

MODEL SIMULATION RESULT
FLOODING DUE TO PUMP SYSTEM FAILURE

(ASSUMING NO DRAINAGE ALONG FIRST CREEK)

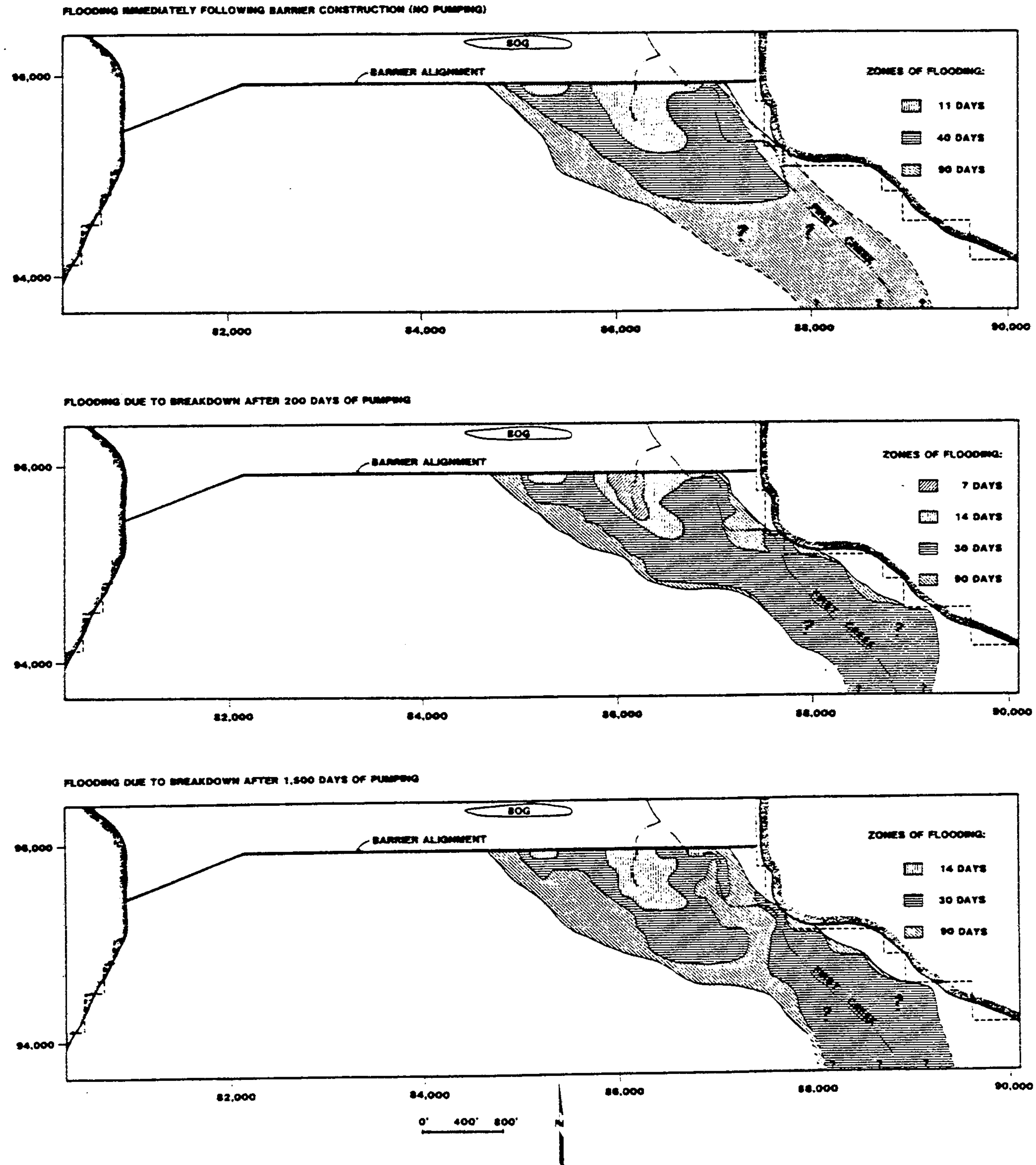


Figure VI-9

square feet and will first occur approximately 1,600 feet from the eastern end of the cutoff wall. The flooded zone will continue to develop with time.

(2) If a total pump well failure occurs after 200 days of operation, flooding will occur almost immediately. A significant flooded zone appears in less than one week.

h. The North Boundary finite-difference model should be used as an operational tool. As the barrier system is operated, the model should be recalibrated to monitoring data which will refine the model's predictive capabilities and assist operations.

i. The influence of dewatering wells on First Creek appears to be minimal. A pump test performed near First Creek from the alluvial aquifer did not indicate a recharge boundary effect after five days of pumping. The soils beneath the creek channel are clayey and must have a relatively low vertical permeability.

j. Design of alluvial dewatering wells is shown in design drawings and described in the specifications. Model predicted well capacities will probably not be achieved in some cases because of irregular clayey zones and cemented sands. As a result, pumping rates will probably have to be adjusted to some degree depending on actual performance in the field. This is not expected to adversely affect operations, but it will require careful adjustment of the system.

k. Twenty-nine new alluvial dewatering wells are proposed for the North Boundary containment system, for a total of 35 when the six existing operating wells are included. Pumping rates were assigned to each

well in such a way as to minimize distortion of the ground water flows while also intercepting the flow across the North Boundary. Projected pumping rates range from 1.0 to 26.2 gpm with drawdowns of 1.42 to 4.84 feet at steady state. These pumping rates and drawdowns are tabulated in the design drawings for each well.

l. Alluvial dewatering wells will be constructed using steel casing with a stainless steel screen of 0.060-inch slot size. Type 316L steel was selected for the screens because of its high corrosion resistance characteristics. Boreholes for construction of the alluvial dewatering wells will be 16 inches in diameter, which will allow a minimum 4-1/2-inch gravel pack around the 6-inch (i.d.) well screen. Screen lengths and placement were determined by constructing geologic profiles along the dewatering well alinement and interpreting bedrock contacts and location of sand lenses from adjacent boreholes. Wherever possible, screens were placed so that pumping water levels would be at or above the top of the screen.

m. Twenty-six new recharge wells are proposed for the North Boundary containment system for a total of 38 when the 12 existing wells are included. Flows from the treatment plant were apportioned among the recharge wells by use of the finite-difference model with the objective of restoring natural flow conditions without flooding. Recharge rates range from 0.4 gpm to 37.0 with increase in head of approximately 0.53 foot to 2.26 feet in the wells. These recharge rates and increases in head are tabulated on design drawings. Flows from the Denver Sand dewatering wells will add a maximum of 31 gpm to the recharge well system. The distribution

of this small increase in flow was not assigned to specific wells and will be determined operationally. In an emergency, the bog could be used for recharge and it could probably accommodate a major part of the recharge water. The bog is well located for this purpose, and if it were used for recharge, the natural flow system would probably be restored a short distance downstream.

n. All recharge wells will be constructed in the alluvial aquifer, using stainless steel screen of 0.060-inch slot size. Wells will be of the gravel envelope type with a 24-inch well bore, for a large effective radius. Screen and casing will be 16 inches in diameter.

D. GROUND WATER CONTAMINATION - ALLUVIAL AQUIFER.

1. Criteria.

a. The containment facility design objective at the North Boundary is to intercept three zones of contamination so that the variable contaminant levels in these zones can be intercepted and treated separately. Water quality studies were performed to determine the extent of contaminant plumes and estimate the mass fluxes of contaminants for each dewatering well.

b. Chemical contamination of the alluvial aquifer ground water in an area between Basin F and the North Boundary was investigated using ground water chemical analysis data bases provided by RMA. Four chemical constituents were investigated in detail. These constituents and the number of wells for which ground water chemical analyses were performed are listed in Table VI-2. These chemical analysis data were first carefully

Table VI-2

CONTAMINANTS INVESTIGATED IN BASIN F TO

NORTH BOUNDARY STUDY AREA

(Wells in Alluvium)

Contaminant	Number of Wells Sampled and Tested	Number of Groundwater Samples Tested
Fluoride	184	1434
DIMP	189	1750
DCPD	184	959
DBCP	188	1750

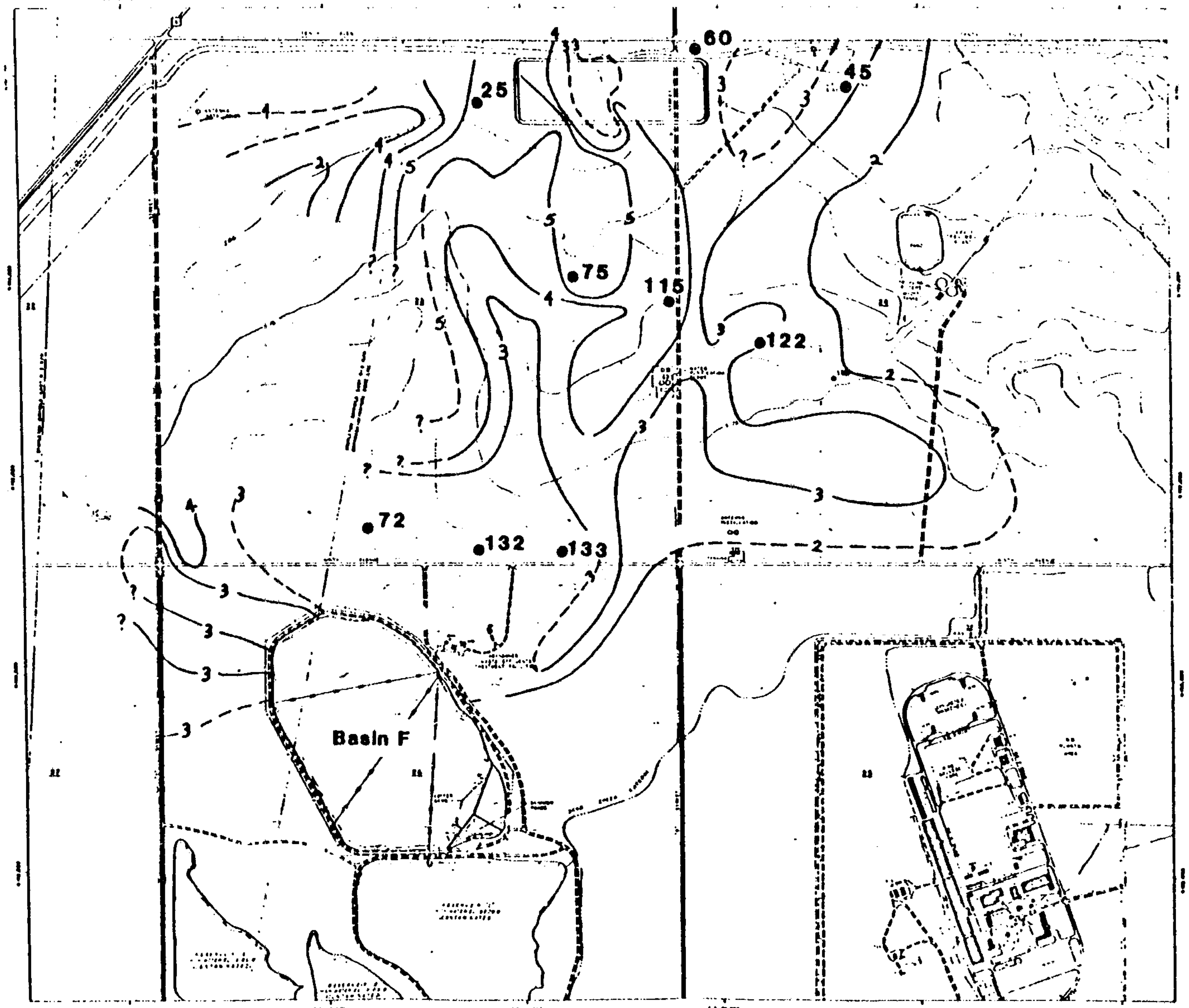
screened to eliminate those data which were obtained from wells placed in the Denver Formation. For purposes of developing contours of present 1979 contaminant concentration levels, average maximum concentrations for wells with 1979 data were used. In addition to the raw data from chemical analyses described above, interpretations of similar data developed by other investigators (WES, 1979; D'Appolonia, 1979; Konikow, 1977) were studied.

c. Major emphasis was placed on developing contours representative of essentially present 1979 contamination levels. Data were not averaged over long periods of time. This is an important consideration. If a contaminant's concentration at a specific location is increasing (or decreasing) with time due to contaminant plume migration and dispersion, then averaging data over a long time period would generally yield an artificially low (or high) concentration level.

d. Chemical contamination contours of three of the four control constituents were developed and are shown on Figures VI-10 through VI-12. DBCP is widely distributed and plumes could not be defined. However, a profile of DBCP concentrations was developed at the barrier location and is described later along with mass fluxes. It should be noted that the contours represent "present day" (i.e. 1979) contamination levels only and are not representative of future contamination levels. Estimation of future contamination levels is complicated by the following factors:

(1) Contaminant plume convection and dispersion phenomena are complicated.

(2) Multiple unknown contaminant sources are probably present or have existed within the ground water system at RMA.

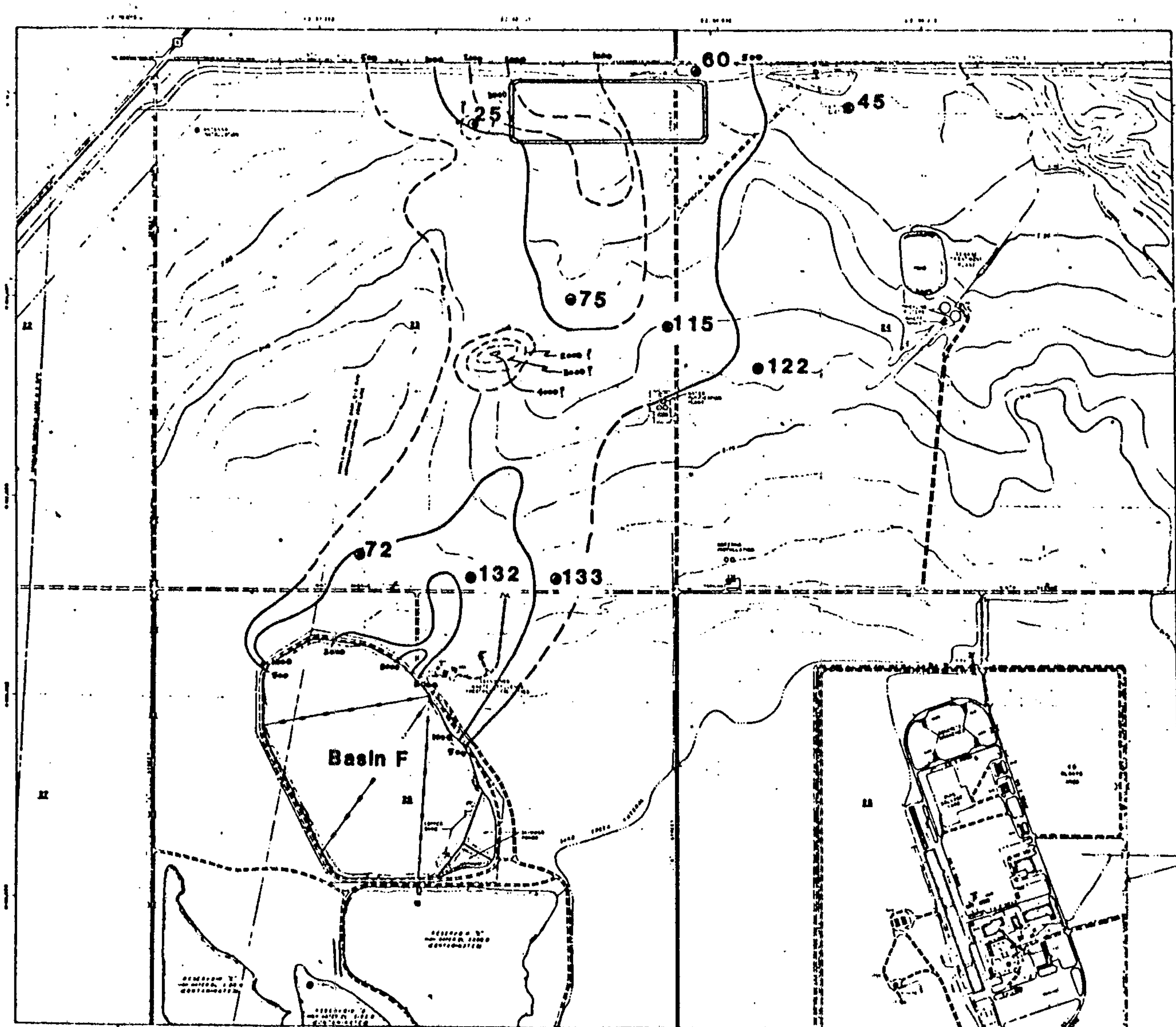


FLUORIDE CONCENTRATION CONTOUR MAP

North Boundary Area

Units in mg/l

Figure VI-10



DIMP CONCENTRATION CONTOUR MAP

North Boundary Area

Units in μg/l

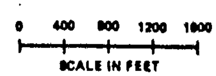
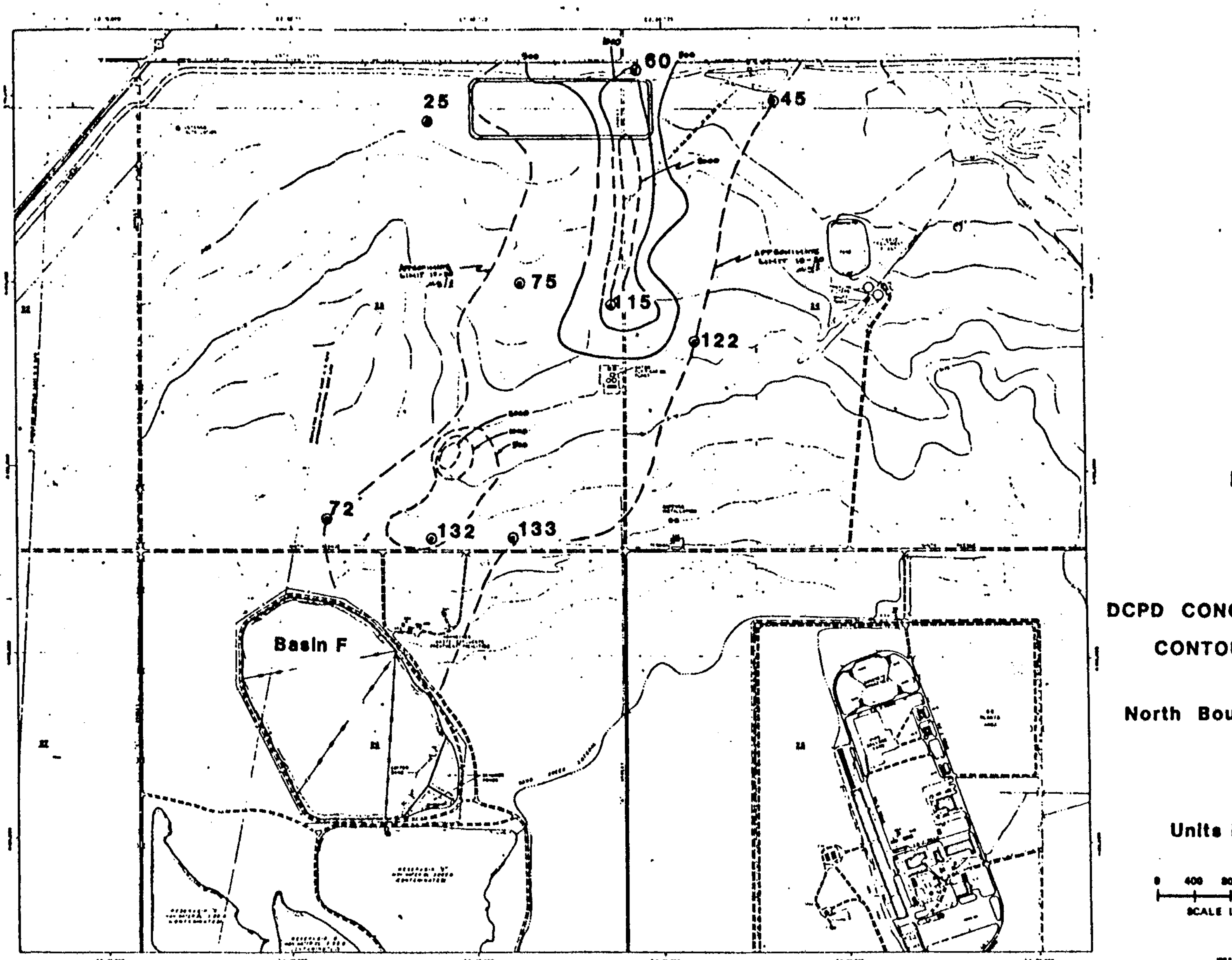


Figure VI-11



DCPD CONCENTRATION CONTOUR MAP

North Boundary Area

Units in µg/l

Figure VI-12

(3) Sorption of contaminants by formation material is probably occurring to some degree.

e. Despite the limitations of the chemical contamination contours noted above, the contours on Figures VI-10 through VI-12 indicate the following general trends:

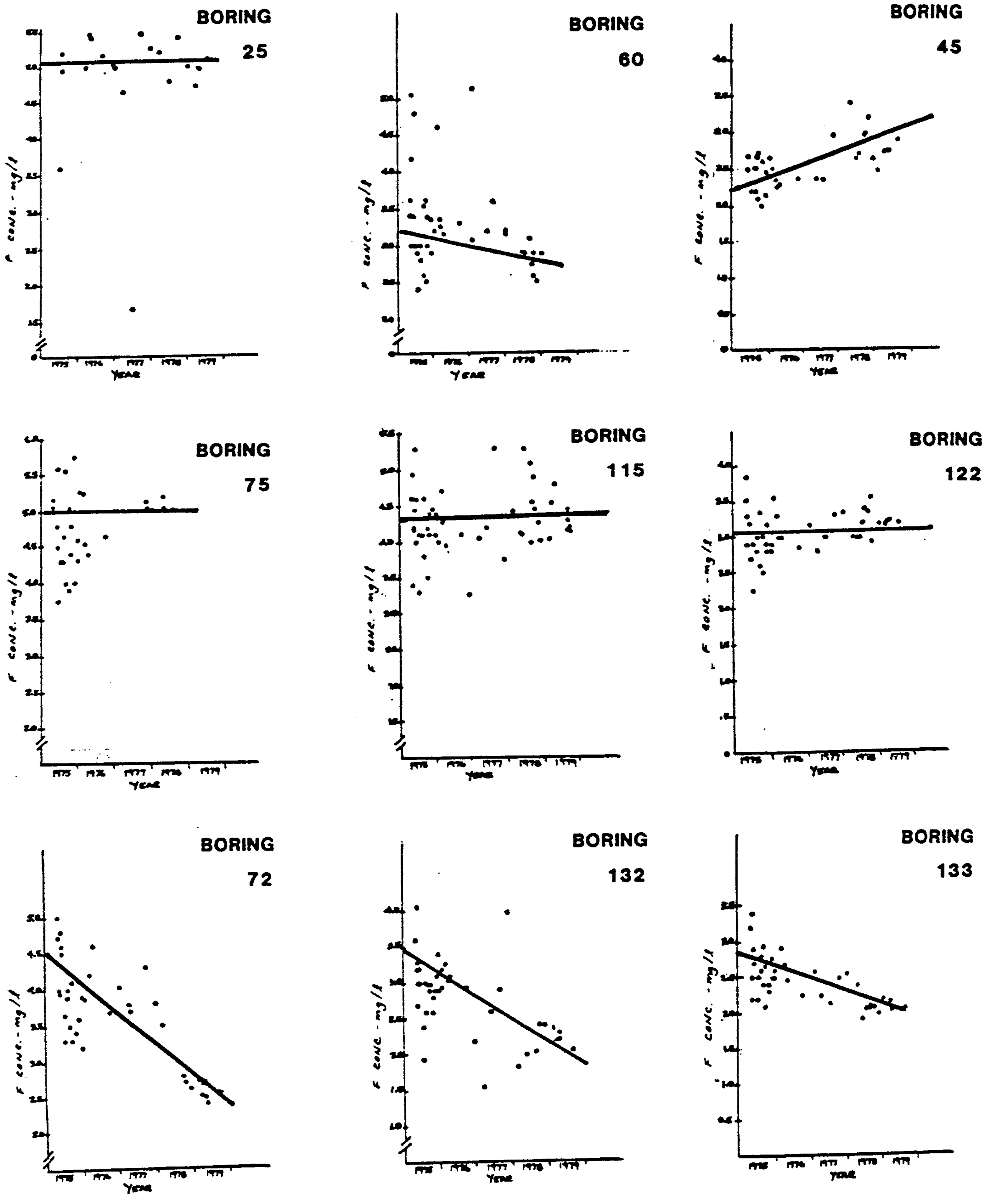
(1) Contaminants are contained in isolated plumes or pulses.

(2) Some contaminant plumes appear to be migrating from Basin F to the North Boundary, while some isolated plumes probably have other sources.

(3) High contaminant concentrations are generally confined to the western portion of the North Boundary.

f. Chemical contaminant breakthrough curves for nine selected wells were developed and studied. The breakthrough curves shown on Figures VI-13 through VI-15 represent the contaminant time histories at the given locations. The nine wells selected for analysis were chosen from a total of 19 wells within the North Boundary area having at least four years of chemical analysis data. The locations of the 19 wells having four years of data are shown on Figure VI-16. The selection of the nine wells chosen from the 19 for analyses was based on their relative position with respect to plume locations and their spatial coverage of the North Boundary area.

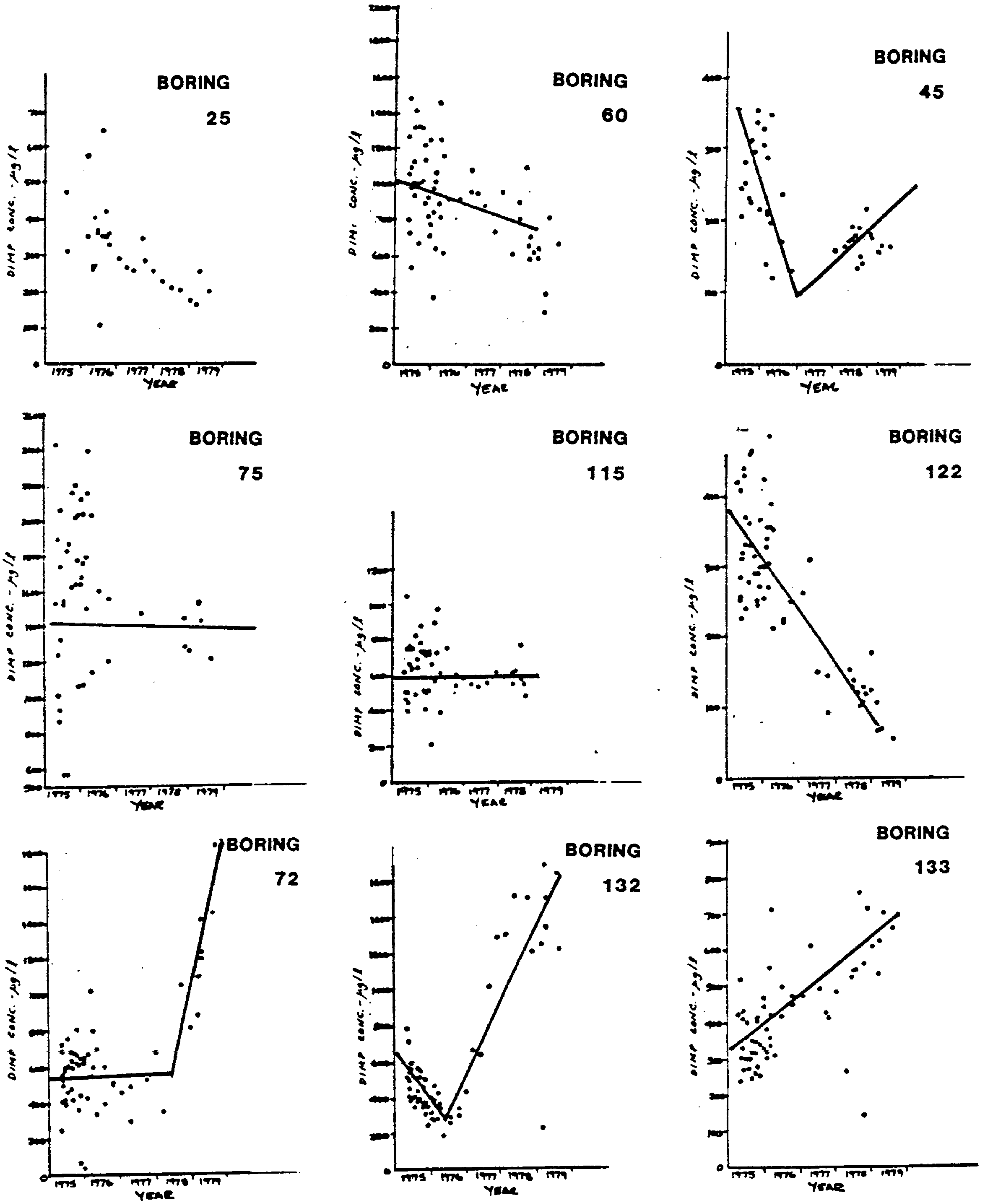
g. Breakthrough curves were developed by drawing straight lines through the rather scattered chemical concentration versus time data shown on Figures VI-13 through VI-15. These lines were used to illustrate general trends in the data and do not represent detailed contamination trends.



BREAKTHROUGH CURVES

FLUORIDE CONCENTRATION - mg/l

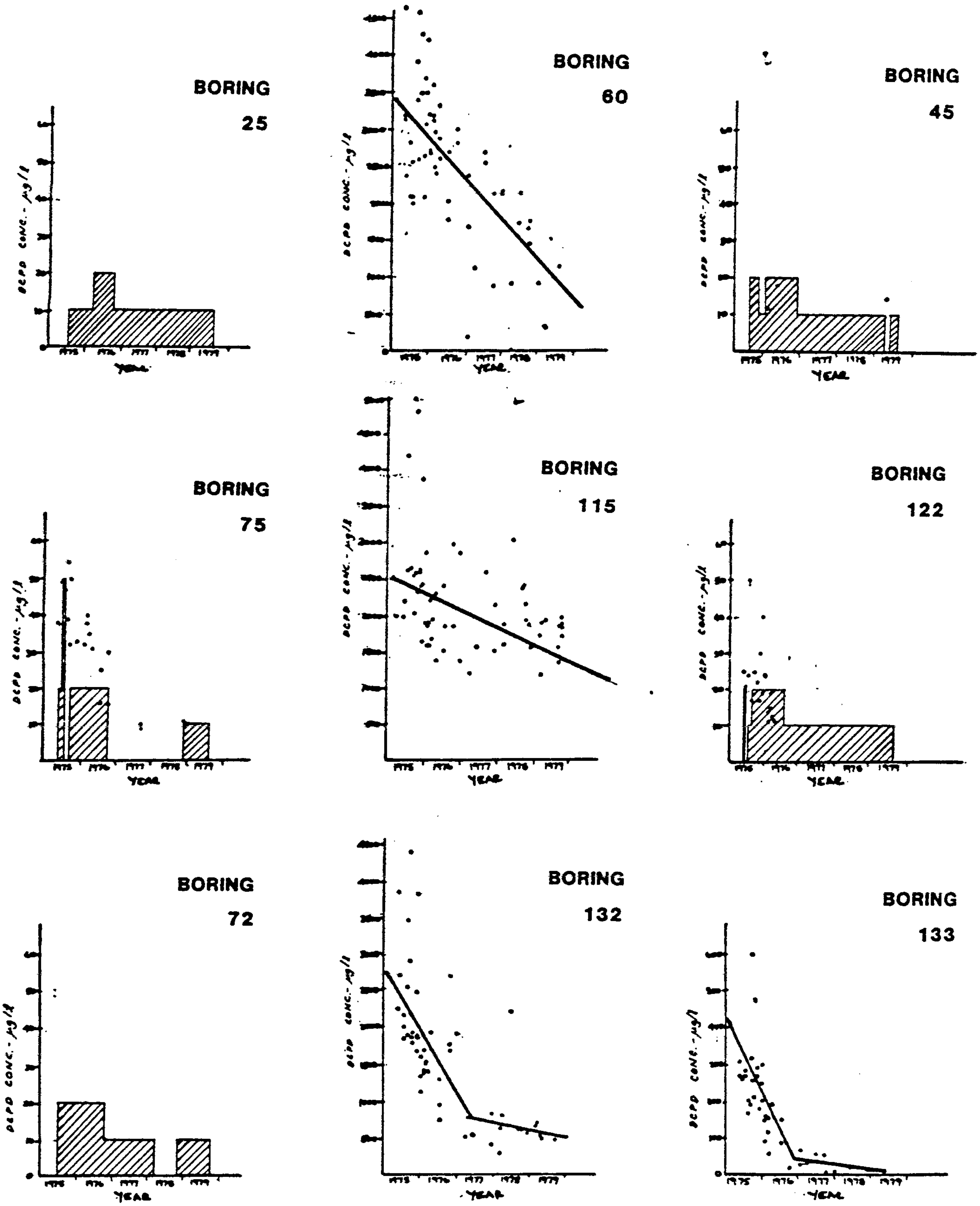
Figure VI-13



BREAKTHROUGH CURVES

DIMP CONCENTRATION - µg/l

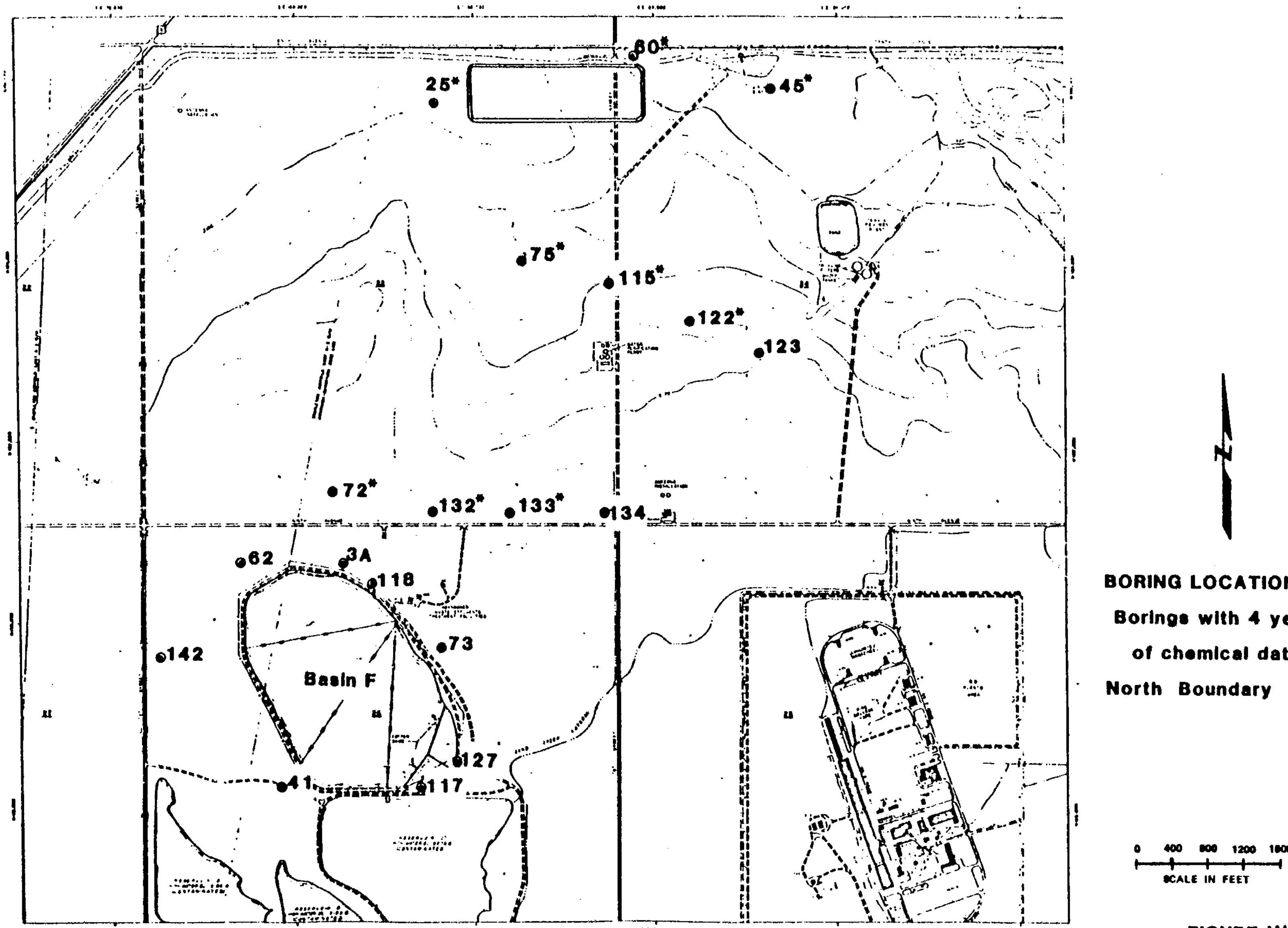
Figure VI-14



BREAKTHROUGH CURVES

DCPD CONCENTRATION - µg/l

Figure VI-15



BORING LOCATION MAP

Borings with 4 years of chemical data

North Boundary Area

FIGURE VI-16

*Indicates that boring was used to develop Breakthrough Curves

2. <u>Analysis</u>.

a. The following observations were made from the chemical analysis data shown in the breakthrough curves and contour plots generated from present 1979 data:

(1) Fluoride

(a) Wells close to Basin F show a general downward trend in concentrations indicating that the plume peak has passed these locations.

(b) Concentration of contaminants in wells midway between Basin F and North Boundary has remained relatively constant within the time period considered. This indicates that the center of plume has been passing these points for some time and concentrations should start to decrease.

(c) Wells within the western portion of North Boundary area indicate constant or dropping concentrations which may be related to the influence of the Pilot Facility.

(d) A Well (No. 45) within the east central portion of North Boundary shows increasing concentrations due to migration of the dispersed plume front.

(2) DIMP

(a) Wells close to Basin F show increasing concentrations and indicate a new plume migration from Basin F.

(b) Wells midway between Basin F and North Boundary show constant or decreasing concentrations.

(c) Wells near the North Boundary show decreasing concentrations to the west and adjacent to the Pilot Plant but increasing concentrations to the east.

(3) DCPD

(a) All wells show a general trend in data. However, contamination should start to increase along North Boundary as a new plume moves northward as shown on the contour map of this constituent.

(4) DBCP

(a) This contaminant could not be contoured and analyzed because of limitations of data.

b. The following conclusions can be made based on the observations stated above and other observations of chemical analysis data.

(1) The breakthrough curves illustrate the variable patterns of migration and dispersion of contaminant plumes.

(2) The contamination levels should not be expected to remain constant with time.

(3) Unexplained trends in the breakthrough curves, contaminant plume migration patterns and isolated contaminant pulses (or slugs) illustrate the complexity of the natural flow system.

(4) Multiple sources have probably contributed to the complex plume pattern. Basin F is one obvious source, but other sources have not been defined in detail.

These conclusions again suggest that estimation of future contamination levels along the North Boundary cannot be accomplished without a

detailed solute-transport model. Only present day 1979 contaminant concentrations can be estimated with confidence. At best, only maximum future concentrations along the North Boundary can be estimated using an understanding of the present ground water flow system and present maximum contaminant concentration existing in the area between Basin F and the North Boundary. An upper limit for maximum future contaminant concentrations of the North Boundary pumping system can be estimated by assuming that: (1) the ground water system will not be greatly affected by the proposed North Boundary slurry trench barrier and associated treatment facilities; and (2) dispersion of contaminants is neglected.

c. Mass fluxes for the four previously mentioned contaminants were calculated for two situations listed below:

(1) Present 1979 contaminant concentrations along the cutoff wall alinement.

(2) Upper limit to probable future contamination concentrations along the cutoff wall alinement.

d. Flux values were calculated by multiplying the pumping rate of each of the 35 dewatering wells by the concentration of the contaminant in the area influenced by the well. The pumping rates and total system discharge were obtained from the finite-difference modeling results. The concentrations of the contaminants were determined differently for the above two cases.

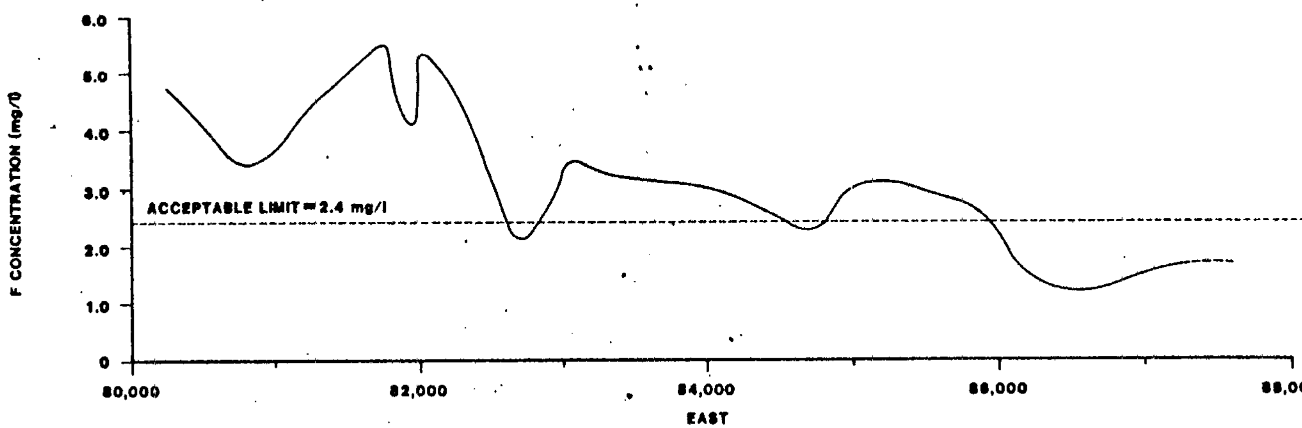
e. Profiles showing contaminant concentrations along the cutoff alinement were developed from the contaminant contour maps previously

described. These profiles are shown on Figures VI-17 and VI-18. A stastical average concentration for the area influenced by each discharge well was calculated from the values on the profiles. To be conservative, this average was weighted toward the value at the dewatering well if this value was higher. The results of these calculations are shown in Table VI-3 for the four chemical contaminants fluoride, DIMP, DBCP, AND DCPD. The sums for the entire system are also shown.

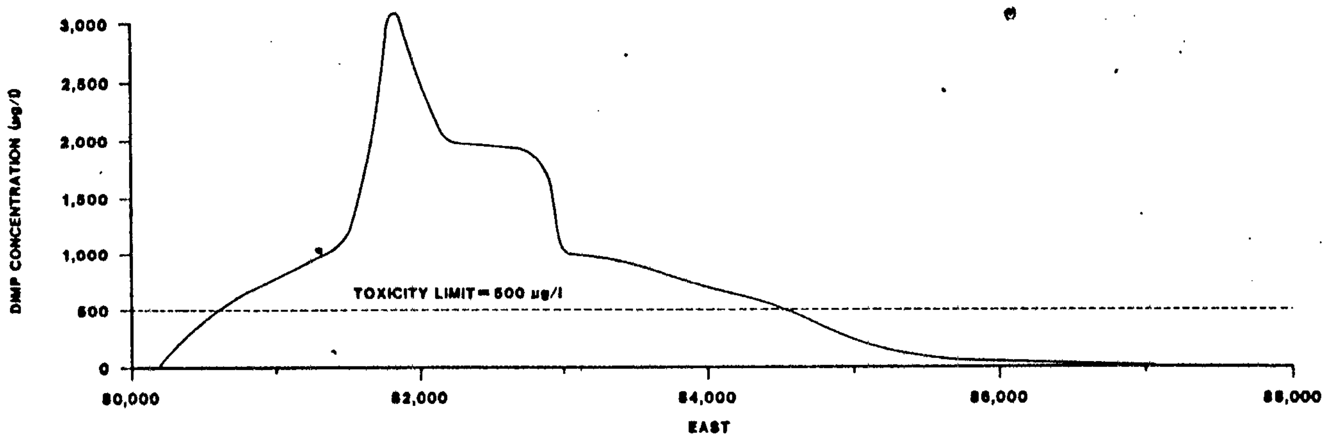
f. Upper limit of probable future contaminant concentrations was estimated by using detailed knowledge of the ground water flow system to project the highest concentrations from the contaminant contour maps to the cutoff wall alinement. This approach is equivalent to assuming that the plumes propagate according to the principles assumed for the finite-difference flow model and ignores the presence of convective or dispersive flow phenomena. This simple approach is presumed to be conservative and the maximum values, as presented in Table VI-4 are considered to be an upper limit of expected concentrations.

g. The values given in Table VI-3 are based on 1979 data and are assumed to be representative of the contamination levels one would presently observe along the trench alinement. The upper limit values given in Table VI-4 are indicative of maximum expected levels but no inference as to when these levels may be expected can be made.

h. It is observed that future levels of DCPD can be expected to increase up to 300 percent with respect to 1979 levels. All other contaminants can be expected to increase only by 10 to 15 percent. This is probably due to the various source and plume propagation conditions of the different contaminants.

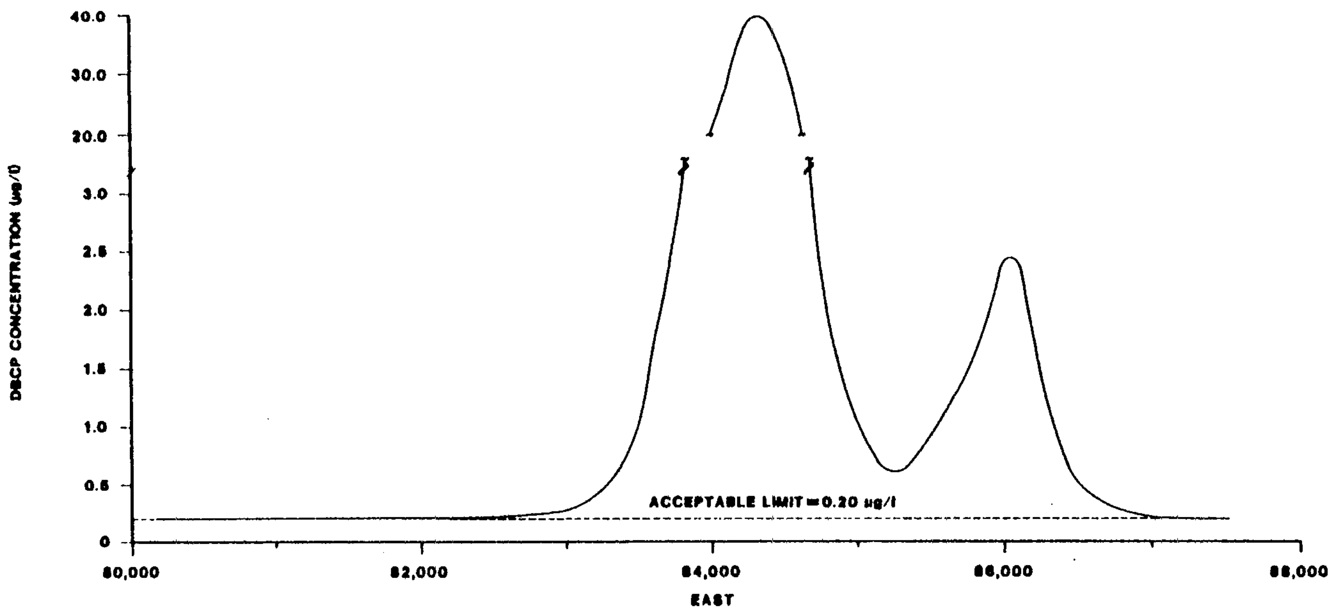


FLUORIDE CONCENTRATION ALONG 95,930 N
YEAR 1979

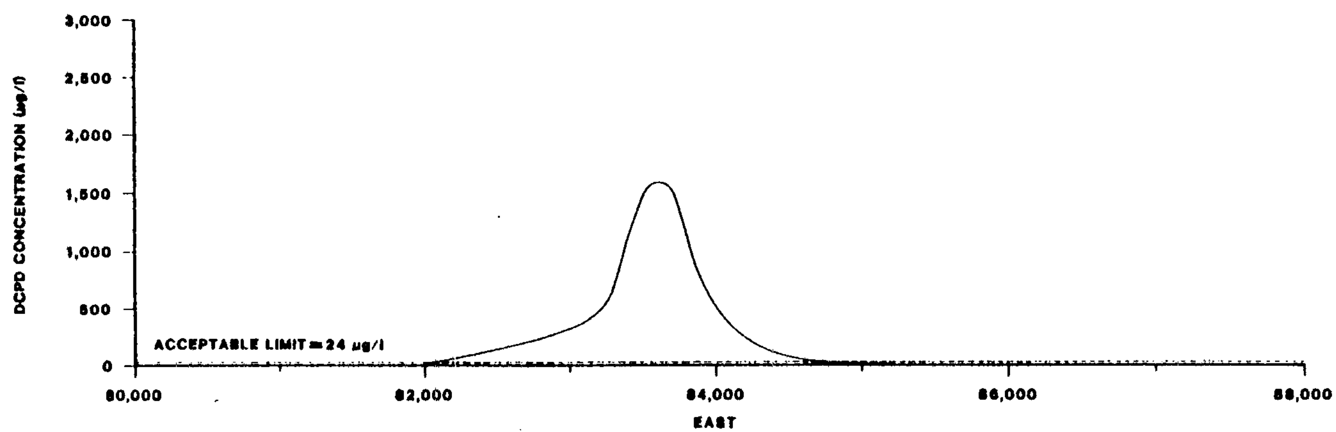


DIMP CONCENTRATION ALONG 95,930 N
YEAR 1979

Figure VI-17



DBCP CONCENTRATION ALONG 95,930 N
YEAR 1979



DCPD CONCENTRATION ALONG 95,930 N
YEAR 1979

Figure VI–18

Table VI-3

PRESENT (1979) CONTAMINANT MASS FLUX
(Using Weighted Average Values from Wells)

Well Number	Pumping Rate Q		Fluoride		Dimp		DCPD		DBCD	
	GPM	Liters/ Day	Average Conc.-gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day
DW-1	3.95	21464	.00342	73.41	.00195	41.85	.00015	3.22	.00000022	.0047
DW-2	5.72	31082	.00240	74.60	.00191	59.37	.00020	6.22	.00000023	.0072
DW-3	8.92	48471	.00275	133.30	.00157	76.10	.00028	13.57	.00000025	.0121
DW-4	11.25	61132	.00334	204.18	.00099	60.52	.00039	23.84	.00000032	.0196
DW-5	12.76	69337	.00327	226.73	.00094	65.18	.00079	54.78	.00000054	.0374
DW-6	14.87	80803	.00315	254.53	.00087	70.30	.00147	118.78	.00000122	.0986
DW-7	16.21	88085	.00310	273.06	.00080	70.47	.00143	125.96	.00000229	.2017
DW-8	16.45	89389	.00305	272.64	.00073	65.25	.00085	75.98	.00001000	.8939
DW-9	17.94	97485	.00296	288.56	.00066	64.34	.00039	38.02	.00002569	2.5044
DW-10	14.78	80314	.00281	225.68	.00061	48.99	.00021	16.87	.00003830	3.0760
DW-11	14.78	80314	.00262	210.42	.00056	44.98	.00012	9.64	.00003903	3.1347
DW-12	20.00	108679	.00241	261.92	.00049	53.25	.00007	7.61	.00003735	4.0592
DW-13	22.84	124112	.00232	287.94	.00040	49.64	.00004	4.96	.00001779	2.2080
DW-14	21.94	119221	.00254	302.82	.00031	36.96	.00003	3.58	.00000200	.2384
DW-15	20.78	112918	.00292	329.72	.00024	27.10	.00003	3.39	.00000117	.1321
DW-16	20.13	109386	.00315	344.57	.00018	19.69	.00003	3.28	.00000078	.0744
DW-17	25.95	141011	.00315	444.18	.00013	18.33	.00003	4.23	.00000068	.0959
DW-18	26.18	142261	.00295	419.67	.00009	12.80		---	.00000093	.1323
DW-19	25.66	139435	.00279	389.02	.00006	8.37		---	.00000131	.1827
DW-20	23.85	129600	.00255	330.48	.00004	5.18		---	.00000193	.2501
DW-21	15.29	83085	.00203	168.66	.00003	2.49		---	.00000234	.1944
DW-22	13.78	74880	.00148	110.82	.00003	2.25		---	.00000185	.1385
DW-23	18.62	101180	.00128	129.51	.00003	3.04		---	.00000092	.0931
DW-24	18.94	102919	.00122	125.56	.00002	2.06	<.00003	---	.00000043	.0288
DW-25	19.13	103952	.00132	137.22	.00002	2.08		---	.00000028	.0291
DW-26	10.60	57600	.00146	84.10	.00002	1.15		---	.00000023	.0133
DW-27	10.00	54340	.00157	85.31	<.00001	0.54		---	.00000021	.0114
DW-28	9.00	48906	.00164	80.21	<.00001	---		---	.00000020	.0098
DW-29	6.00	32604	.00168	54.78	.00001	---		---	.00000020	.0065
DW-30	1.03	5597	.00401	22.44	.00085	4.76		---	.00000020	.0011
DW-31	1.95	10596	.00473	50.12	.00105	11.13	<.00003	---	.00000020	.0021
DW-32	2.98	16193	.00519	84.04	.00164	26.56		---	.00000020	.0032
DW-33	5.51	29941	.00535	160.18	.00270	81.14		---	.00000020	.0060
DW-34	3.97	21573	.00520	112.18	.00236	50.91	.00005	1.08	.00000020	.0043
DW-35	3.91	21247	.00456	96.89	.00198	42.07	.00010	2.12	.00000022	.0047
	ΣQ=485.67 gpm	2639111 ℓ/day		Σflux= 6851.4 gm/day		Σflux= 1128.85 gm/day		Σflux= 517.13 gm/day		Σflux= 17.910 gm/day

Table VI-4

PROBABLE UPPER LIMIT OF CONTAMINANT MASS FLUX
(Based on 1979 Chemical Distribution data)

Well Number	Pumping Rate Q		Fluoride		Dimp		DCPD		DBCD	
	GPM	Liters/ Day	Average Conc.-gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day	Avg. Conc. gm/ℓ	Mass Flux gm/day
DW-1	3.95	21464	.00575	123.42	.003750	80.49	.00200	42.93		
DW-2	5.72	31082	.00575	178.72	.004250	132.10	.002500	77.71		
DW-3	8.92	48471	.00575	278.71	.004250	206.00	.003000	145.41		
DW-4	11.25	61132	.00550	336.23	.002250	137.55	.002500	152.83		
DW-5	12.76	69337	.00450	312.02	.001500	104.01	<.003000	<208.01		
DW-6	14.87	80803	.00430	347.45	.000850	68.68	<.003000	<242.41		
DW-7	16.21	88085	.00375	330.32	.000800	70.47	.002000	176.17		
DW-8	16.45	89389	.00350	312.86	.000750	67.04	.001250	111.74		
DW-9	17.94	97485	.00340	331.45	.000700	68.24	.001000	97.49	Insufficient	
DW-10	14.78	80314	.00330	265.04	.000600	48.19	.000750	60.24	Data Provided	
DW-11	14.78	80314	.00325	261.02	.000550	44.17	.000500	40.16	For	
DW-12	20.00	108679	.00315	342.34		---	.000400	43.47	Analysis	
DW-13	22.84	124112	.00310	384.75		---	.000300	37.23		
DW-14	21.94	119221	.00310	369.59		---	.000250	29.81		
DW-15	20.78	112918	.00310	350.05		---	.000200	22.58		
DW-16	20.13	109386	.00310	339.10		---	.000100	10.94		
DW-17	25.95	141011	.00310	437.13		---	.000020	2.82		
DW-18	26.18	142261	.00300	426.78		---		<1.42		
DW-19	25.66	139435	.00270	376.47		---		---		
DW-20	23.85	129600	.00230	298.08	<.00050	---		---		
DW-21	15.29	83085	.00210	174.48		---		---		
DW-22	13.78	74880		---		---		---		
DW-23	18.62	101180		---		---		---		
DW-24	18.94	102919		---		---	<.000010	---		
DW-25	19.13	103952	<.00200	---		---		---		
DW-26	10.60	57600		---		---		---		
DW-27	10.00	54340		---		---		---		
DW-28	9.00	48906		---		---		---		
DW-29	6.00	32604		---		---		<.33		
DW-30	1.03	5597	.00575	32.18	.002750	15.39	.000550	3.08		
DW-31	1.95	10596	.00575	60.93	.003000	31.79	.000575	6.09		
DW-32	2.98	16193	.00575	93.11	.003750	60.72	.000600	9.72	Insufficient	
DW-33	5.51	29941	.00600	179.65	.003000	89.82	.000625	18.71	Data Provided	
DW-34	3.97	21573	.00600	129.44	.003000	64.72	.000650	14.02	For	
DW-35	3.91	21247	.00575	122.17	.002750	58.43	.001000	21.25	Analysis	
	ΣQ=485.67 gpm	2639111 ℓ/day		Σflux = 7193.49 gm/day		Σflux = 1347.81 gm/day		Σflux = 1576.57 gm/day		

E. GEOTECHNICAL ANALYSIS - DENVER FORMATION.

1. Background.

a. Geotechnical analyses to determine if pollution of the Denver Formation exists, transport mechanisms involved, and how containment can be achieved, if needed, is difficult to analyze because of a number of complications. The water quality criteria selected for control of Nemagon (DBCP) is the detectable limit of 0.2 μg/l. The fairly widespread occurrence of this constituent in the overlying aquifer creates a potential for equally widespread occurrence in the Denver Formation, especially in shallower zones, at or near the detectable limit. Very slight errors due to cross contamination from well construction, sampling or chemical analysis probably have resulted in uncertainties regarding the presence of contamination by Nemagon. In the deeper parts of the formation this constituent has controlled the selection of possible contaminated zones.

b. Transport mechanisms are complicated by the geology of the Denver Formation and a sparsity of data up and downstream from the barrier. Contaminants will follow the more permeable flow paths which are tortuous because of the geometry of the Denver Sands. These sand beds, as described earlier, are lenticular in cross section, but are probably elongated along sinuous or meandering paths. While these sand beds are highly confined where overlain by claystones or siltstones, subcrops are known to exist where sands are in direct contact with overlying highly permeable alluvium that contains the bulk of the contaminant flow. The hydraulics of solute-transport is further complicated by rather extensive jointing and fracturing

of the claystones and siltstones. Available evidence indicates these fractures are relatively tight, but they are capable of transmitting some water. Therefore, subcrops of channeled sands, combined with interweaving of sand channels (resulting in channel sand contacts) and fractures provide transport mechanisms for at least limited contamination from the overlying alluvium.

c. There are several alternatives for designing a containment system for the Denver Formation. These alternatives are listed below.

(1) The slurry cutoff wall can be extrended downward to block all possible or suspected contaminated zones of the Denver Formation. This is obviously the most costly alternative because the slurry trench would have to be extended to depths as much as 105 feet. This would place most of the trench in the Denver Formation which is more difficult to excavate. Also, equally deep dewatering wells would have to be constructed to pump the blocked flow and relatively deep recharge wells would have to be at least considered to restore flows downgradient.

(2) The cutoff wall can be keyed into the first claystone or siltstone encountered below the alluvium-bedrock contact combined with dewatering wells to contain any contaminants in the Denver Formation. This wuld be probably the least expensive solution. However, shallow, low permeability, or thin sands might be difficult to contain with wells because of limited available drawdowns. Also, the risk would be

higher because of the possibility of flow through fractures beneath the cutoff wall. As explained previously, this risk is believed to be low, but there are no quantitative data available to access fracture permeability immediately below the alluvium contact for the barrier extension. There are pump test data that applies to this question beneath the pilot cutoff wall.

(3) The third alternative is to extend the cutoff wall well into the Denver Formation (except for the pilot barrier) to cut off shallow sand zones and reduce the risk of shallow fracture flow. The cutoff wall would be supplemented by dewatering wells to intercept possible contaminated flows in deeper sands below the cutoff wall. This alternative is basically a compromise between (1) and (2) above. Costs are probably intermediate between these two alternatives but certainly closer to (1) above.

d. Alternatives (2) and (3) are not only less costly, but they are also more flexible which is important when one considers the possibility that few or none of the deeper sands are contaminated above drinking water standards for the four control constituents. However, data are reasonably conclusive that organic contaminants have penetrated the Denver Formation at least at low levels of concentrations and the transport mechanisms are available for higher level future contamination at the North Boundary. Therefore, a reasonable means should be available to intercept possible contaminated zones. Dewatering wells offer both the means and the flexibility to expand the containment facility on an as needed basis.

2. Water Quality.

a. Contaminants including fluorides, DIMP, DBCP and DCPD have been detected in Denver Sands at the North Boundary. Contaminant levels are generally low and are erratically distributed in sand lenses ranging from depths 20 to 105 feet below ground surface. In general, more contamination is present to the west of the study area beneath the more concentrated contaminant plumes in the overlying alluvial aquifer.

b. Nemagon (DBCP) is the most prevalent contaminant in the area in the Denver Sands but it usually occurs in very low concentrations near detection limits of 0.2 g/l. Since this is the water quality standard for interception and treatment, it is very difficult to judge if true contamination exists due to possible errors in sampling and chemical analyses. This constituent, therefore, controls the extent of suspected or possible contamination in the Denver Sands.

c. Fluorides, DIMP, and DCPD have only been detected at levels above water quality standards in isolated cases. Fluorides have 2.4 mg/l have only been reported from Wells 991M and 984S. DIMP concentrations above 500 g/l has only been reported from Well 991M and DCPD concentrations above 24 g/l has only been reported in Well 981S. Analyses of samples collected from Wells 1041 and 1045 during pump tests did not reveal concentrations of any of the four constituents above water quality standards. Well 1045 was pumped from a shallow sand that is beneath the existing barrier where contamination levels are high in the overlying alluvium. Also, analyses of samples from newly installed Wells 1017, 1018, 1019, 1021, and 1024 showed concentrations below drinking water standards.

Well 1021 replaces 991M which was thought to be contaminated by well seal failure. So far, this appears to be the case. Except for Well 981, all of the latest chemical analyses indicate water in the Denver Sands below the proposed cutoff wall, meet drinking water standards. This is not conclusive, but it may be significant because the latest samples and analyses should be more reliable with the additional experience developed in sampling and analysis. Interception of Denver Sands may prove that waters generally meet water quality standards. Nevertheless, higher contamination levels may exist upgradient from the barrier and it is prudent to develop facilities for interception combined with monitoring. The Denver Sands constitute very low permeability aquifers, and contaminant plumes will move at extremely slow rates.

d. The extent and geometry of Denver Sands was determined from borehole data and shown in Figure VI-19. Sands deeper than the proposed cutoff wall that may be contaminated are shaded. Dewatering wells have been designed to intercept flows in these sands on an as needed basis.

3. Geohydrology.

a. The geohydrology of the Denver Formation is based on extensive borehole and test data that is unfortunately concentrated along the alinement of the cutoff wall (See Plate 1 in pocket). There is a sparsity of subsurface information upstream and downstream from the barrier alinement. As a result the geometry of members of the Denver Formation can only be depicted in two dimensions as shown on Figure VI-19. The other weakness of the data base is that hydraulic gradients cannot be determined because observation wells are generally alined perpendicular to the direction of

EXPLANATION FOR GEOLOGIC CROSS SECTION ALONG CENTER LINE OF PROPOSED BARRIER

UNITS

SP	Sand, poorly sorted
SM	Silty Sand
SC	Clayey Sand
GP	Gravel, poorly sorted
GC	Clayey Gravel
ML	Silt, low plastic
CL	Clay, low plastic
CH	Clay, high plastic

SYMBOLS

Top of Denver Formation; contact between Alluvium and Denver Formation.

Approximate depth of existing trench.

Depth of proposed trench.

Depth of weathering

Sand lenses in Denver Formation.

Denver sand lenses intercepted by dewatering wells.

Approximate contact separating alluvial clays and silts from alluvial sands and gravels.

Spring, 1979, water levels.

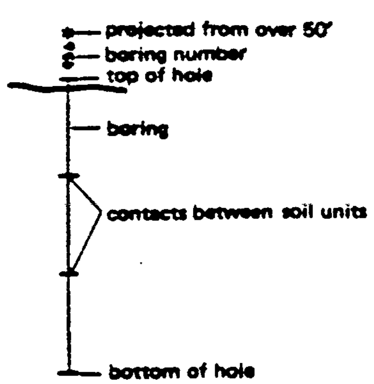


Figure VI-19

flow. This is not considered to be a serious weakness because it is reasonable to assume the gradients in the overlying alluvium are approximately parallel, although piezometric heads are often a few feet lower than the water table in the alluvium. As Geraghty and Miller have shown regionally, the Denver Formation and the alluvial aquifer appear to act together as part of the shallow regional flow system. Consequently, it is highly unlikely the gradients in the Denver Formation at the North Boundary deviate significantly from those in the overlying alluvium.

b. In cross section along the barrier alinement, the geology of the Denver Formation is complicated by lensing or pinching out of sand beds. The large number of boreholes drilled by WES (in 1979) and ESA have resulted in generally very good correlations of beds. Correlations were made using mainly lithologic descriptions of cores and drive samples supplemented by geophysical logs. Resistivity, spontaneous potential and gamma logs were particularly helpful in making correlations. Extension of the sand bed between Boreholes 1012 and 1017 as well as extension of the bed between Boreholes 1005 and 1006 are questionable and are not supported by geophysical log characteristics. Also, there are probably some small sand lenses that are missed by the drilling programs, but these problems are not considered to be serious weaknesses.

c. Available field permeability data is abundant along the barrier alinement in the sand units. WES performed 23 slug tests in isolated zones in 12 borings. In addition, one slug test was run in jointed claystone. The results of these slug tests are shown on Table VI-5. To supplement these data, ESA performed two pump tests to determine aquifer

Table VI-5

Slug Test Results for Hydrogeologic Assessment of Denver

Formation Sands Along North Boundary

Pilot Boring No.	Satellite Boring No.	Screen Depth ft	Flow Type	Fit Compared to Type Curve	Storativity	Transmissivity cm^2/sec	Permeability cm/sec	Aquifer Thickness* ft
885	885-1	42.0- 54.0	Confined	Good/Excellent	10^{-1}	2.46×10^{-2}	$.792 \times 10^{-4}$	10.0
	885-2	80.0- 90.0	Confined	Good	10^{-1}	0.020×10^{-2}	0.0079×10^{-4}	8.2
976	976-1	48.0- 53.0	Unconfined	Fair/Good	--	--	0.788×10^{-4}	3.0
	976-2	61.0- 66.5	Confined	Good	10^{-2}	0.408×10^{-2}	0.288×10^{-4}	5.5
977	977-1	46.0- 50.0	Confined	Fair	10^{-1}	0.198×10^{-2}	0.191×10^{-4}	4.0
	977-2	70.0- 77.0	Confined	Fair	10^{-2}	0.208×10^{-2}	0.115×10^{-4}	10.0
978	978-1	64.0- 74.0	Confined	Good/Excellent	10^{-1}	0.369×10^{-2}	0.142×10^{-4}	6.3
	978-2	105.0-110.0	Confined	Fair	10^{-5}	0.140×10^{-2}	0.108×10^{-4}	5.0
979	979-1	31.0- 35.0	Confined	Good	10^{-4}	147.0×10^{-2}	141.0×10^{-4}	4.0
	979-2	51.0- 64.0	Confined	Good	10^{-1}	0.576×10^{-2}	0.171×10^{-4}	11.2
	979-3	81.0-100.0	Confined	Good/Fair	10^{-2}	0.276×10^{-2}	0.056×10^{-4}	16.0
981	981-1	41.0- 45.0	Confined	Poor	10^{-4}	0.347×10^{-2}	0.334×10^{-4}	4.0
	981-2	70.0- 88.0	Confined	Good	10^{-2}	3.43×10^{-2}	0.736×10^{-4}	16.0
983	983-1	25.0- 30.0	Confined	Good	10^{-8}	1.99×10^{-2}	1.53×10^{-4}	5.0
	983-2	60.0- 65.0	Confined	Fair	10^{-3}	0.116×10^{-2}	0.089×10^{-4}	5.0

Table VI-5 (Continued)

Slug Test Results for Hydrogeologic Assessment of Denver

Formation Sands Along North Boundary

Pilot Boring No.	Satellite Boring No.	Screen Depth ft	Flow Type	Fit Compared to Type Curve	Storativity	Transmissivity cm^2/sec	Permeability cm/sec	Aquifer Thickness* ft
984	984-1	45.0- 53.0	Confined	Good/Excellent	10^{-2}	1.43×10^{-2}	0.69×10^{-4}	8.0
	984-2	70.0- 80.0	Confined	Fair/Good	10^{-2}	0.538×10^{-2}	0.208×10^{-4}	6.5
985	985-1	40.0- 58.0	Confined	Fair/Good	10^{-5}	23.0×10^{-2}	4.94×10^{-4}	20.0
986	986-1	35.0- 40.0	Confined	Fair	10^{-3}	0.25×10^{-2}	0.192×10^{-4}	(Jointed clay)
	986-2	52.0- 62.0	Confined	Fair/Good	10^{-3}	0.433×10^{-2}	0.167×10^{-4}	3.0
987	987-1	75.0- 90.0	Confined	Fair	10^{-1}	8.60×10^{-2}	2.21×10^{-4}	14.0
991	991-1	47.0- 52.0	Unconfined	Good/Fair	--	--	0.133×10^{-4}	3.0
	991-2	68.0- 75.0	Confined	Fair	10^{-1}	3.54×10^{-2}	0.761×10^{-4}	7.0
	991-3	85.0-103.00	Confined	Good/Excellent	10^{-1}	1.65×10^{-2}	0.355×10^{-4}	17.0

*Thickness determined from electrical resistivity logs.

Note: From Hydrogeologic Assessment of Denver Sands Along North Boundary of Rocky Mountain Arsenal by J.H. May, D.W. Thompson, P.K. Law, R.E. Wahl WES Working Draft (January 1980).

TABLE VI-6
SUMMARY OF PUMP TEST RESULTS IN
DENVER SANDS, ROCKY MOUNTAIN ARSENAL

Test No.	Obs. Well	T (gpd/ft)	S	k'/m'	m'	k' (gpd/ft^2)	k' (ft/yr)
1041-1	1042	176	0.0004	0.000176	15	0.00264	0.129
1041-1	985	196	0.00015	0.000082	15	0.00123	0.060
1041-1	1043	243	0.000026	N/A		N/A	N/A
1041-1	1041	148	N/A	(recovery test in pumped well)			
Approx. Average		200	0.0001				
1045-1*	1018*	754*	0.0042	(obscured by boundary effects)			
1045-1*	1046*	682*	0.0051	(obscured by boundary effects)			
	*(Test aborted because constant pumping rate not maintain, results unreliable.)						
1045-2	1018	234	0.0027	(obscured by boundary effects)			
1045-2	1046	184	0.0044	(obscured by boundary effects)			
1045-2	1045	202	N/A	(recovery test in pumped well)			
Approx. Average		200	0.0036				

NOTES:

Average k in vicinity of well 1041 $= \frac{200}{24}$ = 8.3 gpd/ft2 = 405 ft/yr

Average k in vicinity of well 1045 $= \frac{200}{17}$ = 11.8 gpd/ft2 = 576 ft/yr

Average $k_{(horiz)}$ Denver Sands = 10 gpd/ft^2 = 488 ft/yr

Average k' Denver Shale = 0.019 gpd/ft^2 = 0.094 ft/yr

T = transmissibility
S = storage coefficient
m' = saturated thickness of confining layer (Denver Shale)
k' = vertical hydraulic conductivity of confining layer (Denver Shale)
$k_{(horiz)}$ = hydraulic conductivity of aquifer (Denver Sands)

characteristics at the pilot barrier and near First Creek. The results of these tests are summarized on Table VI-6 and field data, calculations, and interpretation curves are appended with design calculations. Except for two slug tests, all field data indicates confined aquifers as would be expected from the geology for those zones not in direct contact with the alluvial aquifer. The two exceptions can be questioned with regard to interpretation of field data. As shown on the tables hydraulic conductivities (field permeability) varied widely for the slug tests whereas the two pump tests were in close agreement for the two widely separated sands. Part of the variance of the slug tests may be due to errors in well construction which is an inherent problem with tests performed without satellite observation wells. However, the variability in hydraulic conductivity is not unreasonable for rocks of this type. For purposes of design analysis, the average hydraulic conductivity of the two pump tests was used which is 10 gpd/ft^2 (488 ft/yr or 4.88 x 10^{-4} cm/sec). This value was selected because: (1) the pump tests were performed in the two most extensive Denver Sands that may be contaminated; (2) the three other potentially contaminated sand units are relatively small in extent; (3) pump tests with observation wells provide more reliable data; and (4) this hydraulic conductivity is more than 10 times the average of the slug tests and its use in computing flows is, therefore, more conservative.

d. Data on the hydraulic conductivity of the fractured claystone is sparse. However, the two pump tests and one slug test indicate that fractures do not destroy the confined aquifer characteristics and that fractures are relatively tight, imparting a very low fracture permeability

to confining layers. Of particular interest is the pump test in the relatively shallow sand beneath the existing pilot barrier. No leakance was observed in this test; indeed, marked impervious boundary effects were apparent from the data plot even though the confining layer is very thin. A slight amount of leakance was detected from testing Well 1041 near First Creek which permitted calculation of the vertical hydraulic conductivity of the confining claystones. The average value calculated from two observation wells was approximately 0.1 foot per year (1 x 10^{-7} cm/sec) as summarized on Table VI-6. The WES slug test in fractured claystones resulted in a hydraulic conductivity of 20 feet per year. This higher value was used to calculate flows through the claystone and siltsone layers of the Denver Formation in order to be conservative again.

e. Lenticular sand beds compose about 20 percent of the Denver Formation beneath the barrier alinement. Assuming a hydraulic gradient of 0.008 (approximate gradient of alluvial flow), with a measured cross sectional area of about 117,000 ft^2 and an average hydraulic conductivity of 10 gpd/ft^2, then the total flow through the Denver Sands beneath the barrier alinement to a depth of 100 feet equals 6.5 gpm. Using the same gradient, a cross sectional area of 456,000 ft^2 and a fracture hydraulic conductivity of 20 feet per year for the claystones and siltsones results in a total flow of 1.0 gpm in these rocks. Even using these high conductivity values the total Denver Formation flow is only about 2 percent of the total system flow in the upper 100 feet beneath the entire barrier alinement. Even if the Denver Formation flow was an order of magnitude greater (x 10), it would only constitute about 15 percent of the total flow

system. The flow through Denver Sands beneath the proposed cutoff wall extension and the existing pilot cutoff wall that might be contaminated is estimated to be 3 gpm using the same criteria as above (see appended calculation sheets).

4. Barrier Extension Containment.

a. The slurry cutoff wall extensions to the southwest and to the east of the existing cutoff wall are designed to penetrate through Denver Formation Sands that are in direct contact with the alluvial aquifer. In addition, the cutoff wall is designed to block selected shallow sand lenses that generally have no information with respect to water quality and might be contaiminated. Also, it is keyed well into claystones and siltstones where sands are absent and generally it penetrates most of the weathered zone. This will also block shallow fracture dominated flow in this zone or at least increase the path of percolation, forcing fracture flow around the bottom of the cutoff wall, thus reducing the flow rate by this mechanism, if it is a significant factor.

b. A supporting system of Denver Sand dewatering wells is designed to selectively intercept deeper flows that may be contaminated. Because of the high degree of confinement in the channeled sand beds, it is assumed that wells must intercept flow in each sand bed individually where contamination is suspected. This premise is probably not entirely true because there is probably is interconnection of sands up and downstream due to the interweaving geometry of these deposits. However, this interconnection can not be proven with field data and confining beds would at least dampen responses to drawdowns in sands not penetrated by dewatering wells.

c. The dewatering wells do not have to dewater the individual sand beds as would be the case in construction excavation dewatering. They are only required to develop a pumping trough or sink in piezometric surfaces sufficient to induce flows to the hydraulic barrier of wells. To do this, considerably more water has to be pumped than naturally flows through the sands, but the pumped quantity required is still relatively small.

d. Large variations in permeability of sand beds presents problems in spacing wells. If the assumed average hydraulic conductivity (10 gpd/ft^2) used for well spacing is in error, then either pumping rates will have to be increased or closer well spacings used. Wells are designed to accommodate increased pumping rates, if hydraulic conductivities are higher than estimated. If lower than estimated hydraulic conductivities are encountered, then closer well spacings will have to be developed by adding wells to the system. Actual well performance coupled with existing monitoring wells will determine the need for increased pumping rates and/or additional dewatering wells. Monitoring of water quality will dictate the need for dewatering since it is suspected that at least some of the sands to be intercepted will prove to contain water that meets quality standards. In this case dewatering can cease and the wells used only for monitoring purposes (all or selected wells).

5. Pilot Barrier Containment.

a. The pilot cutoff wall, 1,500 feet long, was keyed by design only 2 feet into the Denver Formation. As-built drawings are not available, but at least this much penetration was believed to have been achieved. Figure VI-19 shows two small sand lenses that may or may not have been

penetrated by the cutoff wall (detected in Borings 1017 and 978). There could be other similar sands that were not detected. Also, there could be open fractures that would permit flow beneath the cutoff wall. Another concern about the existing structure was a large sand bed separated from the cutoff wall by a relatively thin confining layer as little as 6 feet thick. As a result of these concerns, consideration was given to removing the existing cutoff wall and deepening it to penetrate and block the large sand bed. However, analysis of available data indicates this is not necessary and the existing structure should be adequate.

b. The two thin sand lenses at the base of the existing cutoff wall appear to have direct hydraulic connection with the alluvium and are presumed to contain contaminated water. However, the flow through these lenses and two or three more of similar size would only be a fraction of 1 gpm even if the permeability was 10 times greater than the larger underlying sand which was pump tested. Further, the small amounts of contaminated water that would escape past the cutoff wall wall would be dispersed and diluted with treated recharge water downgradient. Actually, these sand lenses were probably at least partially if not fully penetrated by the cutoff wall which would block or at least partically block their flows.

c. Fracturing is known to exist beneath the existing cutoff wall, but they are believed to be relatively tight and should not result in significant flows bypassing the pilot barrier. If the claystone immediately beneath the cutoff wall contained a high fracture permeability it should have been apparent from the pump test performed on Well 1045. Data plots should have exhibited leakance characteristics, but none were apparent.

Test data indicated a highly confined aquifer with impervious boundary effects. In addition, one of three observation wells (1047) used in this test was screened straddling the top of the Denver Formation in claystone with a short section of screen in the base of the alluvium. This observation well showed no detectable response to pumping the test well even though it was only 11.2 feet to the south.

d. If shallow open fractures exist that do not penetrate the confining claystone, there is still a possibility of small amount of water bypassing the pilot cutoff wall. However, such shallow fractures would be in hydraulic connection with the alluvial aquifer and contaminants would be dispersed by recharge of treated water downgradient. Also, some of this water would be intercepted by dewatering wells upstream because essentially the same stresses would be imposed in shallow fracture flow as on the alluvial aquifer. Further, if open shallow fractures exist, there would be a tendency for the bentonite slurry to seal them because of the high heads due to slurry levels and the density of the slurry. This sealing effect should at least be more effective than slush grouting of a fractured foundation because of the relatively high heads imposed on any open fractures.

e. Early during design studies, a decision was made to investigate the feasibility of containment with the use of dewatering wells to intercept flow through the large sand bed that occurs 6 or more feet below the base of the alluvium below the pilot cutoff wall. At this time there was no information available on the quality of water in this sand and it was assumed to be contaminated because of its shallow depth. Three monitoring wells and a test well were installed in this sand and chemical

analyses of water samples to date indicate that the water meets quality standards. However, this sand may be in hydraulic connection and correlate with a sand monitored in Well 981S. Monitoring data from Well 981S consistently indicates contamination above quality standards. Based on the latest available water quality information, this is the only case where contamination is clearly a problem below the existing or proposed cutoff walls. A hydraulic barrier has been designed consisting of dewatering wells to contain flows in the sand beneath the pilot barrier.

6. Well Barrier Design.

a. Denver Sands were selected for containment on an as-needed basis as shown (shaded) on Figure VI-19. These sand beds occur beneath both the pilot barrier and barrier extensions. Mechanisms for contamination of these sands, described previously, are movement downward from subscrops combined with fracture flow. The velocity of movement through the sands is probably on the order of 40 feet per year based on a hydraulic conductivity of 488 feet per year and a hydraulic gradient of 0.008. The vertical velocity through fractures could be as much as 10 feet per year based on head differences in the alluvial aquifer and the Denver Formation, and a hydraulic conductivity of 20 feet per year.

b. Hydraulic design criteria were based on the two pump tests of Wells 1041 and 1045 realizing that greater variations in hydraulic conductivity may exist as indicated by WES data (see Tables VI-5 and VI-6). The hydraulic conductivity from the two pump tests ranged from 8.3 to 11.8 gpd per square foot and an approximate average value of 10 gpd per square foot was used for well barrier design purposes. The hydraulic conductivity

was multiplied by the sand thicknesses to obtain transmissivity values. A storativity of 0.004 was used which is the highest of the two average values obtained and is conservative. The sand beneath the pilot barrier exhibited impermeable boundary effects which will increase the pumping depression, but this was ignored in design, again to be conservative.

c. Distance drawdown calculations were used to estimate dewatering well spacings and design pumping rates and pumping levels. These calculations are appended with design calculations. Calculations indicated that after 10 days of pumping, a cone of depression would extend 387 feet from each well penetrating the thicker sands (wells pumping 2 gpm and one well pumping 5 gpm). After 100 days the pumping cone would extend to 1,225 feet from each of these wells. For the wells pumping 1 gpm from thinner sands, the radius of the cone of depression for each well after 10 days of pumping is estimated to be 212 feet and 671 feet after 100 days of pumping. A maximum spacing of 200 feet was selected based on these calculations. Pumping cones would extend somewhat further upgradient and less than calculated downgradient. The spacing is marginal for the thin sands for 10 days or less of pumping and it is possible that closer spacings may be required by addition of wells if sands are found to be contaminated during operation of the well barrier.

d. A total of 19 dewatering wells were designed to pump a total of 31 gpm or about 10 times the natural flow rate. The large number of wells are necessary to develop a deep sink to intercept contaminants during relatively short pumping periods. Because of severe boundaries, interference and drawdown calculations are very approximate and much of the

design is based on judgment. It is estimated that wells will pump between 10 and 100 days before maximum design drawdowns in the wells are reached. When that point is reached, the wells will have to be cycled on and off. This cycling or intermittent pumping will reduce the average total pumping rate, estimated to be about ± 15 gpm.

e. Because dewatering wells are designed for low pumping rates, slotted 4-inch diameter PVC casing will be used for screened intervals in a 9-inch well bore. The 2.25-inch annular space will be gravel packed to prevent caving of clay shales into the screened intervals. A 10-inch PVC conductor casing placed in a 16-inch well bore and grouted in place with cement by the mud displacement method will be used to seal the well from the overlying alluvial aquifer. The conductor casing bore will be drilled with a mud rotary method. Drilling mud is necessary for the mud displacement method of installing the cement seal. The 9-inch bore will be drilled by the air rotary method for least disturbance and development of aquifer sands. Details are shown on design drawings and described in the specifications.

f. The dewatering well system is designed to operate on an as-needed basis and also serve to monitor contaminants. Dewatering wells should be monitored closely for contaminant concentrations. If contamination is not present, they should be shut down and used only for periodic monitoring. Pumping will stress these sands and could induce more rapid movement of contaminants into the piezometric sink from subcrop areas.

F. SLURRY TRENCH CUTOFF WALL.

1. Criteria.

a. Develop a 3,840-foot eastern extension of the existing slurry cutoff wall to provide a near impermeable barrier which will prevent ground water migration through the alluvial aquifer.

b. Develop a 1,400-foot southwest extension of the existing slurry cutoff wall to prevent ground water flow around the west end of the pilot barrier.

c. The trench for the extended cutoff walls will be excavated through the alluvial aquifer and into the Denver Formation (bedrock) to the depth shown on the design drawings.

d. The alluvial soils within the trench alinement consist of a mixture of clays, silts, sands, and gravels and vary in thickness from 13 feet to 20 feet in the southwest extension and from 12 feet to 28 feet in the eastern extension. Within the trench alinement the water table is generally located 2 to 10 feet below the existing ground surface.

e. In order to evaluate various techniques of the slurry trench cutoff barrier concept and to develop general information on slurry trench specifications, the following tasks were carried out:

- A review of published literature.
- Discussions with various contractors and engineers knowledgeable in the field.
- Collection, review, and evaluation of a number of specifications on the slurry trench method.

f. A field exploration program including laboratory testing was performed to provide supplementary design data. This program included 30 boreholes along the trench alinement, sieve analyses of soils, and unconfined compression tests of rock cores. Results of the laboratory tests are presented on the design drawings. A geologic section along the alinement is shown on Figure VI-19.

g. For this project a soil-bentonite slurry trench was selected to contain ground water flow under the anticipated gradients imposed by operation of the discharge and recharge wells. This procedure is probably the most common method which has been used in the past to cut off or slow down flow of water or other liquids through the ground. Calculations (appended) indicate that flow through the cutoff wall will total less than 0.1 gpm to the north. Model simulations indicate that the hydraulic gradient through the cutoff wall will slope to the north.

h. There are several types of bentonites available for use in slurry trenches. Basically, however, all of them have the property that in the presence of water they well substantially by absorption of water molecules into the face of the montmorillonite clay platelets which largely make up the bentonite. By properly mixing the bentonite with water, a viscous slurry is formed which is mobile and has a very low permeability. With the slurry placed in a trench, it exerts a lateral fluid pressure on the sides of the trench and serves to stabilize the opening which might otherwise collapse. The basic characteristics desired of the slurry are:

- It must have enough density and viscosity to support the trench walls without excessive slurry loss into the soil.

- It should be mobile enough to be displaced when necessary, by a slurry-backfill mixture and to fill voids in the trench walls.
- It should have a very low permeability.
- It should be stable and durable and not flocculate out of solution.

A bentonite consisting of an ultrafine sodium catron-base montomorillonite powder (Wyoming-type bentonite) that conforms to the standards set forth in the American Petroleum Institute Specifications BA was specified for this project. The specifications for the slurry trench cutoff barrier were written with the objective of economically and safely achieving these charactertistics.

i. The solid that is mixed into the backfill is most often specified as to grain size and allowable soil types. The addition of the soil has the purpose of reducing the amount of bentonite used, adds body to the slurry and reduces the trench compressibility. To achieve these objectives, soil types with either excessive silt or clay content or organic content should not be used. Also, to maintain impermeability, high percentages of gravels or larger particles should not be allowed.

j. Based on the above requirements clayey soils contained within the alluvium and the majority of the excavated bedrock will not be suitable for use or backfill. The material to be used as backfill shall be thoroughly mixed with the slurry and shall conform to the following gradation requirements.

Screen Size or Number (U.S. Standard)	Percent Passing by Dry Weight
1-1/2 inch	90-100
3/4 inch	80-100
No. 4	50-100
No. 30	25-70
No. 500	10-25

k. An estimate of the quantities of material to be excavated from the trench was made. In addition, the results of laboratory tests were used to estimate the volume of excavated material which would be suitable for backfill. These calculations indicated that a total of about 15,000 cubic yards of material would be excavated with approximately 4,000 cubic yards suitable for use as backfill. Additional calculations indicated that another 3,000 to 4,000 cubic yards of imported backfill would be required to provide the necessary quantity of soil to be mixed with the slurry for use as backfill.

G. NORTH BOUNDARY MONITORING SYSTEM.

1. Criteria.

a. Monitoring of water quality and water levels is required to provide the effectiveness of the North Boundary containment system and to provide data for dewatering, treatment, and recharge operations. Monitoring is required both onpost in the North Boundary area and offpost to the north in Sections 13 and 14.

b. Periodic water quality data are needed in both the alluvial aquifer and in the Denver Sands to determine the extent of contamination and concentration levels flowing to the containment system from upgradient.

Similarly, these data are needed downgradient to establish time-concentration trends with barrier system operation. Detailed water quality data is needed at the alluvial dewatering wells to divert intercepted flow to the appropriate treatment modules.

c. Periodic water level data are needed to demonstrate the degree to which the natural flow regime is disturbed by barrier operation both upstream and downstream of the barrier. Detailed water level monitoring is needed near the cutoff wall to control pumping rates and drawdowns of the alluvial dewatering wells, to prevent flooding over the cutoff wall, and to balance pumping with natural flows within design limitations. Dewatering wells must pump an estimated 110 percent of natural flows until near steady state is reached (up to 4-1/2 years). Gradually pumping rates can then be reduced to close to natural flows. However, the First Creek bog area is very sensitive to flooding because of the high water table and there is little margin for error. One positive factor, however, is that the flood prone area has the best quality water, and flooding in this area would not be as serious as in other zones of the flow system.

d. Water quality in the Denver Sands needs to be monitored to better define the depth, extent and levels of contamination with time. There is a downward component of flow from the suspected contaminant sources on the arsenal into the Denver Formation. Ground water velocities are generally much slower in the Denver Sands because of lower hydraulic conductivities. Therefore, it is possible that higher contaminant concentrations have not reached the North Boundary. Also, the full depth of contaminant flow or potential flow is unknown at the barrier location.

Sampling and testing has only been performed to depths of about 100 feet, and it is unknown if contaminants exist at greater depths. Full understanding of Denver Sand contamination is a regional problem that is currently under study.

2. Analysis.

a. The North Boundary monitoring system will incorporate existing wells both onpost and offpost along with an array of new wells. Additionally, arsenal-wide monitoring (360-degree program) with supplement the North Boundary system. It is assumed that the existing wells along the pilot cutoff wall working surface and perimeter road alinements will be destroyed during construction. Attempts will be made to preserve as many existing wells as is practical, but provisions have been made to replace existing wells with new monitoring wells in the areas of construction. The monitoring schedule for water levels and water quality is described in detail in the "North Boundary Containment System Monitoring Program, Rocky Mountain Arsenal", a part of the permit application to the State of Colorado for subsurface disposal systems. A total of 60 new monitoring wells are proposed, as shown on the design drawings.

b. Typical designs were developed for shallow and deep monitoring wells. The shallow wells are designed to monitor the alluvial aquifer, or the first Denver Sand encountered if overlying alluvium is unsaturated or absent. The deep monitoring wells are designed to monitor sand layers overlain by another aquifer, either Denver Sands and/or the alluvial aquifer. These wells will be sealed against cross contamination from any overlying aquifer(s). A third type of monitoring well will be

installed just north of the existing cutoff well to monitor water quality in the weathered claystone. These wells will be screened immediately below the base of the cutoff wall in the first claystone of the Denver Formation and will be sealed off from the overlying alluvium and underlying Denver Sands.

c. Monitoring wells will be installed as single wells, or as clusters of two or three wells, each monitoring a different zone. Wells in a cluster will be no less than 10 feet and no more than 25 feet apart and may be installed in any geometric arrangement. Denver Sand clusters will consist of two deep monitoring wells, one perforated in one of the upper Denver Sand units, and the second in a lower bedrock sand. Clusters of three wells will have a shallow monitoring well in addition to the two deeper Denver Sand monitoring wells. Test wells will be drilled for final design of all monitoring wells except for shallow wells within 100 feet of the cutoff wall.

d. Shallow monitoring wells will be constructed using a 16 to 18-inch diameter well bore and 4-inch Schedule 80 PVC casing with a gravel envelope. All joints will be threaded to avoid contamination from PVC cement. The borehole will be drilled by the reverse rotary method, without drilling fluid additives which could distort water quality measurements. The 4-inch casing will be perforated with milled slots for an open area of approximately 1.36 percent. The upper 5 feet of the annular space will be filled with cement to form a seal against infiltration of surface water.

Shallow monitoring wells located offpost will have locking caps to protect against vandalism. A total of 41 shallow monitoring wells are planned: 40 installed singly and 1 in a cluster with 2 deep monitoring wells. Construction details for shallow monitoring wells are shown on the design drawing and described in the written specifications.

e. Deep (Denver Sand) monitoring wells will be constructed using a 16 to 18-inch diameter borehole for the conductor casing, and a 9-inch diameter borehole for the well casing and slotted pipe. The 10-inch conductor casing will be installed to a depth just above the top of the sand zone to be monitored, and grouted in place using a mud displacement method. A 9-inch hole will be drilled through the sand zone using the air rotary method, and Schedule 80 PVC casing and milled slots will be installed. Sections of casing and slottedpipe will be threaded to avoid contamination from PVC cement. A uniform sand will be tremied around the casing as a formation stabilizer, to prevent caving of less tightly cemented sections of the Denver Sands, siltstones, and claystones. The formation stabilizer will be brought up to no more than 15 feet above the base of the conductor pipe. The annular space above this point will be grouted off to prevent leakage of surface water into the casing and to keep PVC cement used on conductor casing joints from coming into contact with the ground water. Deep monitoring wells will be installed in clusters, with a total of 16 new Denver Sand monitoring wells to be constructed. Offpost deep

monitoring wells will have locking caps. Construction details for deep monitoring wells are shown on the design drawings and described in the written specifications.

f. Three monitoring wells are planned for the Denver Formation claystone, immediately north of the existing cutoff well. They will be constructed in the same manner as deep monitoring wells, using a 10-inch diameter conductor casing and a 4-inch diameter well casing. Construction details are shown on the design drawings and described in the written specifications for Denver Sand Monitoring Wells.

CHAPTER VII

ROADS, DRIVE, PARKING AREA, AND DRAINAGE

A. PERIMETER AND ACCESS ROADS AND BUILDING 808 ACCESS DRIVE.

Perimeter, access roads, and Building 808 access drive were designed for one-way traffic with 12-foot wide aggregate surface pavement and 4-foot wide aggregate paved shoulders. The pavement design was based on design class F, Category I, and the total compacted aggregate thickness is 6 inches. A subgrade CBR of 5 was used.

B. D STREET EXTENSION.

D Street extension was designed for one-way traffic with 16-foot wide aggregate surface pavement and 4-foot wide aggregate paved shoulders. The pavement design was based on design class F, Category I, and the total compacted aggregate thickness is 6 inches. A subgrade CBR of 5 was used.

C. PARKING AREA.

The parking area (expanded Building 808 access drive) was designed with aggregate surface pavement based on design class F, Category I, with a total compacted aggregate thickness of 6 inches. A subgrade CBR of 5 was used.

D. DRAINAGE.

Drainage shall be accomplished with stream channels, ditches, and culverts located appropriately. The levee containing First Creek flood flows was designed for a 10 year return interval event with 2 to 2-1/2 feet of

freeboard. The levee will protect against the 100 year flood event with less than 1 foot of freeboard. The design storm for drainage culverts was the 10 year return interval event.

CHAPTER VIII

PERMITS AND REGULATIONS

A. SUBSURFACE DISPOSAL. A permit issued by the Division of Administration of the State Health Department is required for the construction and/or operation of a subsurface disposal system in the State of Colorado. The definition of a subsurface disposal system is given in Section 7.2 of the Colorado State Rules for Subsurface Disposal. Issuance of a subsurface disposal system permit follows approval of the application for permit by the State Water Quality Control Commission. The decision by the Commission to accept or reject an application for permit is based upon compliance with Section 7.2 of the State rules which states that issuance is based upon whether or not the subsurface disposal system "will pollute any waters of the State or that the pollution resulting therefrom will be limited to waters in a specified limiting area from which there is no risk of significant migration and the proposed activity is justified by the public need."

Application for a permit should be in report form and contain all information requested in Section 7.2.4 "Application Filed with Division," included in the State rules.

Specific information pertaining to the degree of treatment which should be obtained at Rocky Mountain Arsenal prior to subsurface disposal was stated in a letter dated 27 May 1977 from the Colorado State Department of Health to Colonel Byrne of the Rocky Mountain Arsenal.

B. WATER QUALITY CONTROL. A permit issued by the State of Colorado Water Quality Control Division is required for point discharge of a

liquid wastewater to the waters of the State of Colorado. The permit application is submitted to the Water Quality Control Division who reviews it and then submits it to the Water Quality Control Commission with either an approval or non-approval recommendation. The Commission considers the application, holds public meetings if necessary, and finally approves or disapproves the application. If approved, the Division issues the permit.

The Tri-County Health Department should be contacated once the waste discharge has been defined and disposal plans have been developed. However, if the State requirements have been met, the Tri-County Health Department should present no problems.

C. AIR QUALITY CONTROL. Air pollution in Colorado is controlled by the Colorado Air Pollution Control Act of 1970. The Common Provisions Regulation provided by Section 66-31-8 of the Act contains definitions, statement of intent and general provisions applicable to all emission control regulations adopted by the Colorado Air Pollution Control Commission.

An Emission Permit will be required at Rocky Mountain Arsenal for earth moving, grading, and site preparation. A permit is required prior to ground breaking.

The State Air Pollution Control Division reviews the permit application and performs a preliminary analysis of the effect of the proposed source on ambient quality and the adequacy of emission control. Based on the analysis the Division will accept or reject the application and impose permit conditions.

D. ENDANGERED SPECIES ACT. The Endangered Species Act of 1973, as amended through 1978, is administered through the United States Fish and Wildlife Service in Denver.

Since an EIS is required, the Corps will request a list of the species and proposed species that may be endangered or threatened by the project. The Corps is required to prepare a biological assessment of the project area of influence. This biological assessment is forwarded to the Fish & Wildlife Service with a determination of effect. If there is no effect and the F&WL Service concurs, the project proceeds. If there is an effect, the Corps requests consultation with the F&WL Service and the Service has to prepare a biological opinion within 90 days. If the biological opinion says there is jeopardy to an endangered species, alternatives are presented, evaluated, and discussed with the Corps. If a conflict still exists, the Corps can request a variance.

CHAPTER IX
LIST OF SPECIFICATIONS

DIVISION 1 - GENERAL REQUIREMENTS

- 1A Special Provisions
- 1B Warranty of Construction (to be provided by COE)
- 1C Environment Protection
- 1D Special Safety Requirements

DIVISION 2 - SITE WORK

- 2A Removal and Disposition of Materials and Equipment
- 2B Excavation, Filling, and Backfilling for Buildings
- 2C Excavation, Trenching, and Backfilling for Utilities Systems
- 2D Excavation and Backfilling Working Surface, Slurry Trench
- 2E Clearing and Grubbing for Roads and Structures
- 2F Grading
- 2G Gravel Surfacing
- 2H Seeding
- 2I Storm-Drainage System

DIVISION 3 - CONCRETE

- 3A Concrete (For Building Construction)

DIVISION 4 - NOT USED

DIVISION 5 - METALS, STRUCTURAL AND MISCELLANEOUS

- 5A Miscellaneous Metal

DIVISION 6 - NOT USED

DIVISION 7 - NOT USED

DIVISION 8 - NOT USED

DIVISION 9 - FINISHES

9A Painting, General

9B Decorating Schedule (Interior Design Schedule)

DIVISION 10 - SPECIALTIES

10A Slurry Trench Ground Water Barrier

DIVISION 11 - NOT USED

DIVISION 12 - NOT USED

DIVISION 13 - SPECIAL CONSTRUCTION

13A Metal Buildings

13B Shallow Monitoring Wells

13C Denver Sand Monitoring Wells

13D Denver Sand Dewatering Wells (DW 36 to DW 54)

13E Alluvial Dewater Wells

13F Recharge Wells

DIVISION 14 - NOT USED

DIVISION 15 - MECHANICAL

15A Gas Fitting

15B Well Pumps

15C Pumps, Water, Vertical Turbine

DIVISION 15 - MECHANICAL (Continued)

- 15D Waterlines
- 15E Heating Systems, Direct Gas-Fired Units
- 15F Pressure Vessels for Storage of Compressed Gases
- 15G Identification of Piping

DIVISION 16 - ELECTRICAL

- 16A Electrical Work, Interior
- 16B Electrical Work, Exterior